DETECTION and ESTIMATION

of

INFLAMMABLE GAS & VAPOUR
IN THE AIR

CLOWES
and
REDWOOD

THE DETECTION AND MEASUREMENT OF INFLAMMABLE GAS AND VAPOUR IN THE AIR.

METHANE AND PETROLEUM VAPOUR FLAME-CAPS OVER THE STANDARD HYDROGEN FLAME.

A. Standard hydrogen flame in air free from gas or vapour.
B. Flame-cap with 0·25 % of marsh gas, or 0·05 % of pentane vapour.
C. „   „ 0·5 %   „   „   „

D. Flame-cap with 1·0 % of marsh gas, or 0·3 % of pentane vapour.
E. „   „   2·0 %   „   „   „   0·6 %   „   „
F. „   „   3·0 %   „   „   „   0·8 %   „   „

(Adapted from Mr. Boverton Redwood's work on Petroleum, by permission of the Authors and Messrs. C. Griffin & Co., Limited.)

THE

DETECTION AND MEASUREMENT

OF

INFLAMMABLE GAS AND VAPOUR

IN THE AIR

BY

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WITH

*A CHAPTER ON THE DETECTION AND MEASUREMENT
OF PETROLEUM VAPOUR*

BY

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Capio Lumen

PREFACE.

THIS little book is intended to sum up briefly the results of investigations which have involved much thought and experimental work on my part for several years. Some of the matter has never yet been published; the rest has been scattered over the Proceedings of several of the scientific societies of this and other countries. The attempt is now made to bring the information together in connected form, and to render it more generally available and useful.

The form in which the work is cast enables the reader to gather a general and continuous account of the subject-matter by reading through the Chapters consecutively. If he requires more detailed information, he can obtain this by referring to the Appendices following the Chapters. In these Appendices the original papers are printed in full, and newer matter is frequently added. The very full illustration of the text by diagrams will, it is hoped, add much to its intelligibility.

The detection and accurate measurement of small quantities of firedamp in the air of the coal-mine was the problem originally attacked. This has been solved

by the introduction of the use of a standard hydrogen-
flame. The striking imperfection and inadequacy
of the procedure still commonly adopted in this
country is made evident in the text.

The new method which was found suitable for fire-
damp was naturally extended to coal-gas, water-gas,
and other combustible gases. Mr Boverton Redwood,
working in conjunction with the author, has also
rendered the hydrogen test available for the detection
and measurement of petroleum vapour in the air.
Mr Redwood has contributed a special Chapter
describing the apparatus which he uses for this
purpose, and his general method of procedure.

The book deals mainly with combustible gases.
Amongst these carbonic oxide is included, and a
summary is given of the very important work recently
carried out by Dr Haldane in connection with the
poisonous properties and the detection of this gas.
It was deemed well, however, to include also carbonic
acid gas, which is frequently met with in the same
atmospheres as are examined for combustible gases,
and occurs also as a product of their combustion or
explosion. The general subject gains in completeness
by this addition, although it leads to a departure from
the title-matter of the book.

Much original literature treating of the subject in
question had to be hunted up and studied by the
author. He felt that he might render a service to
those interested in the matter by publishing the refer-
ences to these sources of information. They appear,
accordingly, under the heading " Bibliography."

All the measurements were originally made in centimetres and millimetres, according to the very convenient decimal system. Most of these have been converted into inches for the convenience of English readers. It is much to be regretted that this conversion should at the present time be a necessity.

My acknowledgments are due to the Councils of the Royal Society and of the Society of Arts for permission to reprint my papers, which originally appeared in the Proceedings of these Societies, and for permission to use the illustrative figures from these papers.

I am also indebted to Messrs Waterlow & Sons for the successful production of the coloured frontispiece.

FRANK CLOWES.

University College,
 Nottingham, *July* 1896.

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INFLAMMABLE GASES.

CHAPTER I.

CONDITIONS OF THEIR EXPLOSIBILITY IN AIR.

ANY gas or vapour, which can be kindled or burnt in air, may give rise to danger from fire and from explosion. It is only necessary that the gas should be mingled with air in the requisite proportion, and kindled, in order that it may acquire the power of burning rapidly; an explosion may then be the result. The gaseous mixture in such a case burns throughout with great rapidity, and the flame in passing through the mixture will heat, burn, or scorch objects with which it comes in contact, besides causing danger by its violence, and by the suffocating or poisonous nature of its after-products. The character and violence of the explosion will vary much, according to the proportions in which air and gas have been mingled. The conditions under which the mixture is fired will also influence the result.

Careful experiments have been made (see Appendix, p. 6), to determine the proportions in which different combustible gases must be mingled with air in order to furnish explosive mixtures. These experiments were carried out with undried gases, and with mixtures made at the ordinary temperature and pressure of the air. The results which were obtained are summarised in the following table :—

A

Limiting Explosive Mixtures of Various Gases with Air.

Combustible Gas Used.	Percentage of Gas mixed with Air.		Method of Kindling.
	Lower Explosive Limit.	Upper Explosive Limit.	
Methane, or Marsh-gas {	5	13	Upward.
	6	11	Downward.
Coal-gas (Nottingham) {	6	29	Upward.
	9	22	Downward.
Water-gas (Artificial)	9	55	Upward.
Hydrogen	5	72	,,
Carbonic oxide	13	75	,,
Ethylene	4	22	,,
Acetylene*	3	82	Downward.

It will be understood that the lower proportion of inflammable gas represents the minimum proportion, which, when mixed with air under ordinary conditions, will burn rapidly, and will, under certain conditions, produce explosion.

If the proportion of inflammable gas mixed with the air is less than this in amount, the mixture will only burn in the immediate neighbourhood of the kindling flame, and the mixture will not burn throughout.

If, on the other hand, the proportion of inflammable gas in the air exceeds the maximum quantity given in the above table, the gas will only be kindled and burn where it is in contact with an additional supply of air.

All proportions of gas intermediate between these limits are explosive when mixed with air. Accordingly, the probability of an explosion being caused by the kindling of any of these inflammable gases in the air is greatest when the explosive limits referred to above are most widely removed from one another, since this gives rise to the possibility of a larger number of explosive mixtures being produced. The danger of explosion is, for this reason, least in the case of methane, and greatest in the case of hydrogen.

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* This case is complicated by a somewhat explosive separation of the acetylene itself into its elements.

A further consideration as regards the risk of an explosion occurring is the temperature necessary for kindling the explosive mixture. Here, again, methane is the least dangerous gas, since it possesses a high temperature of ignition. Further, methane of all these combustible gases appears to be most slowly ignited. It requires to be in contact with a source of heat for an appreciable length of time before it becomes kindled.

All these conditions therefore tend to lessen the risk of an explosion being caused by a mixture of methane with air, and therefore to reduce the number of colliery explosions. But it must be remembered, on the other hand, that mixtures which cannot be fired when the flame is applied at their upper surface, may be fired from below, and this is the method of firing which would probably occur in the coal-mine.

Of the gases which are mentioned in the above table, few occur singly under conditions which are likely to give rise to danger. Methane is the dangerous gas of the coal-mine, and hydrogen is now prepared for use when a high temperature flame is required, while carbon monoxide occurs in various gaseous fuels and in the products of some colliery explosives.

More commonly, however, the combustible gases are present in a mixed state, as they are found for example in water-gas and in coal-gas. The proportions in which these constituent gases were present in the water-gas and coal-gas, referred to in the table on page 2, were as follows :—

COMPOSITION OF NOTTINGHAM COAL-GAS.

Olefine hydrocarbons	5.3
Oxygen	0.2
Nitrogen	5.5
Hydrogen	48.2
Carbon monoxide	6.6
Methane, or Marsh-gas	34.2

COMPOSITION OF THE WATER-GAS.

Hydrogen	49.6
Carbon monoxide	40.8
Carbon dioxide	2.6
Nitrogen	7.0

The coal-gas which was used was that supplied by the ordinary street mains in Nottingham. The water-gas was an artificial mixture prepared for the purpose ; it had the average composition of commercial water-gas.

Mr Boverton Redwood has determined the proportion of inflammable vapour from light petroleum oil, which must be mixed with air in order to furnish an explosive mixture. The results of his experiments will be found on page 195.

It should be added that the minimum proportion of gas, which is explosive when kindled in mixture with air, is very considerably reduced if fine dust is present in the air. It has been shown by Abel that the presence of finely divided incombustible mineral dust disseminated through air causes the air to be explosive when it is brought in contact with a flame, even when it contains less than 2 per cent. of fire-damp. Galloway has proved that less than 1 per cent. of firedamp may be exploded when it is mixed with air charged with finely divided coal-dust. It will be seen, therefore, that the presence of fine dust in the air, more especially of fine combustible dust, exerts a powerful effect in making gaseous mixtures, which are in themselves non-explosive, explode in the presence of a flame.

Sir Frederick Abel reported to the Home Secretary, as the result of his experiments made after the Seaham Colliery explosion, on 8th September 1880, that "the proportion of firedamp required in a mine to bring dust readily into operation as an explosive material, when thickly suspended in air, borders upon, and is even sometimes below, the smallest amount (about 2 per cent.), which can be detected in the atmosphere of a mine by the most practised observer with the use of the Davy lamp." He further states, "such dust particles need not be inflammable nor combustible to produce the result named."

Since contact with an ordinary illuminating flame is sufficient to kindle any of the explosive mixtures already referred to, it is evidently dangerous to enter air which may contain inflammable gas with a light produced by a naked

flame. The electric glow-lamp, in which the incandescent filament is enclosed in a vacuum within a glass envelope, is probably the most safe source of light in an atmosphere which may become explosive. But the ordinary illuminating flames are also rendered safe under ordinary conditions if they are enclosed in a suitable safety-lamp, such as is used in the coal-mine. The explosive or inflammable atmosphere becomes kindled on entering such a lamp, but its flame immediately extinguishes the flame of the lamp, and becomes itself also extinguished in the best forms of miners' safety-lamp.

It is noteworthy that these safety-lamps possess the advantage over the electric lamp of indicating the dangerous nature of the atmosphere by the extinction of their flames. The flame of such a lamp even serves to indicate the presence in the air of a proportion of combustible gas which is too small to give rise to danger. The change of appearance of the lamp-flame is sufficient in experienced hands to indicate not only a small proportion of inflammable gas or vapour, but even under suitable conditions to measure its amount with accuracy.

APPENDIX TO CHAPTER I.

The Limiting Explosive Mixtures of various Combustible Gases with Air. (Trans. Fed. Inst. Mining Engineers, vol. ix., pp. 373, 382.)

By Frank Clowes, D.Sc.

It is evident that there will be some one proportion of an inflammable gas in air which will lead to the most violent explosive effect when the mixture is kindled. But it is known that mixtures containing both larger and smaller proportions of the gas are also capable of being exploded by contact with a flame. The object of the series of experiments, the results of which are here described, was to determine the least proportion of the gas and the largest proportion of the gas, which, when mixed with air, are explosive at ordinary atmospheric pressure. These are termed the limiting explosive mixtures.

The mixtures were made in a glass cylinder of known capacity, 3 inches in diameter, and closed at one end. A volume of water equal to that of the combustible gas to be introduced was poured into the jar, and a light xylonite ball, whose volume had been allowed for in taking the capacity of the cylinder, was dropped in. The jar was then inverted with its open mouth in a pan of water, and the remainder of the water was replaced by the combustible gas. The mouth of the cylinder was then closed with a glass plate. After the closed cylinder had been removed from the water, the air and gas were thoroughly mingled by causing the ball to run up and down inside some twenty times.

The cylinder was then removed into a dark room, and a small Bunsen atmospheric gas-flame was brought to its mouth.

If a sheet of flame travelled quickly through the whole length of the cylinder, the mixture was considered to be combustible independently of the external atmosphere. Such a mixture, although it burnt silently in the small mass contained in the cylinder, would undoubtedly produce explosive effects if it were kindled in larger quantity.

If the mixture refused to kindle in contact with the flame, or if it simply burnt slowly as the external air reached it, it was considered to be non-explosive at ordinary atmospheric pressure.

It was found that the mixtures were more readily kindled upward by a flame introduced at the bottom than downward by

a flame introduced at the top.   Accordingly, the composition of the limiting explosive mixtures varied according as the firing was upward or downward.

The experiments were carried out with several different combustible gases, and with coal-gas.   The limiting explosive mixtures varied in their proportion of gas to air when different gases were employed.

In order to measure accurately small volumes of inflammable gas in making the mixtures, the gas was diluted with nine times its volume of air.   In this way a tenfold volume could be dealt with.   Allowance was made for the air thus introduced with the gas, in calculating the composition of the mixture to be experimented with.

The results obtained by repeated experiments made with the same gas were concordant.   In every case the next percentage of gas, below or above as the case may be, failed to fire back.

The conclusions drawn from the experimental results, which are given in tabular form on page 2, are as follows :—

1. When mixed with atmospheric air at ordinary atmospheric pressures, different combustible gases show different limiting explosive proportions.

2. The range between the lower and upper explosive propor-tions is least in the case of methane or firedamp.   The range is widest in the case of acetylene, but hydrogen and carbonic oxide show an almost equally wide range.   The limits in the case of water-gas are widely separated ; with coal-gas the range of explosibility is less.

3. The tendency to explode is greater when the mixture is fired from below than when it is fired from above.   Hence the lower limit mixture contains less gas, and the upper limit mixture contains more gas, when the mixture is fired below than when it is fired above.

4. The probability of an explosion occurring, when a gas is mixed in unknown proportion with air and fired, is diminished as the limits of explosibility approach one another.   Hence the gases which were employed in these experiments may be placed in the following order of increasing danger :—Marsh-gas, ethylene, coal-gas, water-gas, carbonic oxide, hydrogen. The danger is also greater when the flame is applied to the bottom of the mixture than when it is applied to the top.

GAS-TESTING IN THE COAL-MINE—HISTORICAL INTRODUCTION.

A BRIEF and general summary is given here of the methods which have been employed for detecting methane or marsh-gas in the coal-mine at different times. Those methods only are referred to which give at least a rough means of measuring the percentage of gas present, and which have more or less come into use in the coal-mine.

1. Flame-Cap Test.—The original and earliest method for detecting the presence of inflammable gas in the air of the coal-mine consisted in observing the appearance of a candle-flame which was burning in the atmosphere for illuminating purposes.

It was noticed that when a candle-flame was carried into air containing 4 or 5 per cent. of methane or marsh-gas, careful observation detected the mixture of air and methane burning at the tip of the candle-flame. The appearance presented by the burning mixture was that of a very pale conical flame surmounting and partly surrounding the upper part of the candle-flame. This pale flame received the very appropriate name of the "flame-cap."

The extreme pallor of this cap caused it to be easily overpowered by the brightness of the candle-flame. The cap gained in intensity as the proportion of gas in the air increased, and was only seen when the proportion

of inflammable gas in the air approached closely to the dangerous minimum explosive limit of 5 per cent. The cap was then as large and as luminous as was possible, but in order to render it visible, it was found necessary to reduce the size and light of the candle-flame as much as possible by trimming the wick, and to shield the dazzling light of the flame from the eye. If the gas was present in larger proportion than 6 per cent., the cap left the candle-flame and passed as a flame through the atmosphere.

This flame-cap test for the presence of the inflammable gas was a good and convenient one, but it was very far from being as sensitive as it should be. For purposes of safety it is necessary to be able to detect "gas" clearly and unmistakably when its proportion falls far below 3 or 4 per cent., and this is impossible by the candle-flame test.

The use of the illuminating oil-flame in the safety-lamp for the purpose of testing for gas, apart from its greater safety, presented no great advantage over the candle-flame for gas-testing. The size of the flame in the lamp could be more readily and rapidly altered in size than the candle-flame by drawing down or pushing up the lamp-wick, but the lamp-flame as it is ordinarily used in a Davy or Clanny lamp did not prove to be appreciably more delicate than the candle-flame as a means of gas-testing.

The flame-cap test is, however, still in use, and it will be shown later on that this test for gas has been greatly improved. In its most recent form it is capable of furnishing results of the greatest delicacy and accuracy when it is applied to gas-testing. Trials of the ordinary oil-lamps now in use for illuminating purposes showed that pitmen could not see a cap when 2 per cent. of gas was present; while with the best form of hydrogen lamp they easily saw 0.25 per cent.

2. Diffusion-Test.—Another method of gas-testing depended on utilising the property, which a gas lighter than air possesses, of passing spontaneously into air more rapidly

than air passes into the gas. This superior rate of "diffusion" of the lighter gas causes it to pass into the interior of an aneroid barometer, furnished with a porous biscuit earthenware back, more rapidly than the internal air of the aneroid passes out. Accordingly, such an aneroid, which contains air free from gas, indicates a rise of pressure when it is brought into air containing a lighter gas. The extent to which the change of pressure proceeds becomes not only an indication of the presence of the lighter gas, but may be applied to measure the proportion of the gas which is mingled with the air.

The above statement briefly indicates the construction and principle of action of several forms of this gas-indicator which are still more or less in use.

It will be noticed that they indicate rise of pressure when they are brought into atmospheres containing a gas lighter than air, such as methane or coal-gas. They would give the contrary indication, due to reduced pressure, in the presence of inflammable paraffin vapour which is heavier than air, or in the presence of carbon dioxide and other heavy non-inflammable gases.

This is one of the serious drawbacks to the use of this indicator. Its indications are in no way directly related to the inflammable nature of the gas which the apparatus is intended to detect, but a measurement is made of the density of the mixture of gas and air as compared with that of air itself.

Now, inflammable gases and vapours vary widely in their densities, and therefore give correspondingly varying indications in the testing apparatus; and, although the apparatus may be graduated for each of several different inflammable gases, its indications become entirely untrustworthy if these gases are mixed with others of density different from their own, whether they are inflammable or not. Thus the indication of a dangerous proportion of light methane-gas in the air may be altogether masked by the simultaneous presence in the air of petroleum vapour, or of carbon dioxide.

This instrument is also considerably influenced by the dampness, density, and temperature of the external air, as well as by the presence in the internal air of other gas, which must occur in carrying out a series of tests. If the internal air is much colder or warmer than the external atmosphere which is to be tested, as must be the case when the test-apparatus is transported from one place to another, or if gas-free air cannot be introduced into the instrument after each test, the indications of the apparatus will be altogether fallacious.

The results obtained by this form of apparatus, even by those who understand the many and serious causes of error to which it is subject, involve great delay, and are attended with considerable uncertainty.

It has been urged that this indicator cannot furnish correct indications of the amount of inflammable gas in the air of the coal-mine, because other inflammable gases and vapours are present besides methane, and these are possessed of higher density than methane. Hence an instrument graduated to give percentages of methane would not truly indicate the true total quantity of inflammable matter in the air.

Beyond doubt, heavy petroleum vapour is present in the air of certain special coal-mines, and is well known to be there. But the statement that hydrocarbons of greater density than methane are ordinarily present in the air of coal-mines has not been established beyond dispute. If it were established, it would prove another objection to the use of this indicator.

3. The Pitch of a Small Organ Pipe varies when it is blown by gases of different densities. Accordingly, a small pipe, which gives a note in unison with a tuning-fork when it is blown with air, will give a note which is out of unison with the fork when it is blown with air containing a gas which is lighter or heavier than air.

Advantage has been taken of this fact to construct a

gas-indicator; and it has been suggested that the percentage of methane in the air of the coal-mine may be judged by counting the number of "beats" produced when the pipe is blown with the air in the mine.

The apparatus has been recently modified by using two precisely similar pipes, and blowing one with air free from gas, and the other with the air of the mine.

These apparatus possess the same objections as the forms of apparatus which depend upon the principle of diffusion. Their indications do not depend directly upon the inflammable and explosive nature of the gas which is to be tested for. They are disturbed or neutralised by the presence of other gases of different density, and by differences of temperature. Further, the more recent apparatus requires a large supply of pure air, and this is inconvenient to transport.

4. The Electrical Detector is free from the above sources of disturbance and error, and proceeds upon the sound principle of directly utilising the heat produced by the burning of the combustible gas present in the air for detecting and measuring the "gas."

Two platinum wire spirals are made to glow with precisely equal brilliancy by the passage through them of an electric current. One of these coils glows in a small sealed vessel of air, the other glows in the air which is to be tested for inflammable gas. If any inflammable gas is present in the air which is being tested, this gas burns in contact with the surface of the glowing wire. The heat produced by the combustion raises the temperature of the wire, and causes it to glow more brightly. Hence the "exposed wire" glowing in the air containing combustible gas becomes brighter than the "protected wire" glowing in pure air. A simple device serves to measure the difference in brightness of the platinum coils, and since this difference increases as the quantity of inflammable gas in the air increases, a measure of the proportion of "gas" present in the air may be obtained.

This apparatus is much more delicate in its indications than any of those already referred to. It presents practical inconveniences which have proved a hindrance to its general adoption. But it is further subject to the two following causes of uncertainty and inaccuracy.

1. It is to be noted that when the "exposed coil" is giving its greatest brilliancy in air containing the highest proportion of gas which can be shown by the apparatus, this brilliancy will be diminished by an increase either in the proportion of air or in the proportion of the inflammable gas ; decreased brilliancy is thus producible in two precisely opposite ways. The indications of the apparatus can therefore only be relied upon when the percentage of gas present in the air is known to be far below the minimum explosive proportion.

2. A more serious cause of error, however, has been discovered by Mr James Grundy. He finds by careful experiments that the electrical resistance of the exposed wire is subject to very great variation during use. This variation influences considerably the light which this wire spiral emits when it is heated by the passage of the electric current. Since the resistance of the covered spiral remains unchanged, the apparatus often yields results which are quite inaccurate when they are read off upon the scale. The only check on such variations consists in testing and adjusting the apparatus frequently in pure air. Now pure air is not always obtainable when it is required for this purpose, and the test is therefore often carried out under conditions of uncertainty, which render its results of little value.

5. The Complete Combustion of the Combustible Gas (Methane) in air is attended with Reduction in Volume, or its equivalent Decrease of Pressure.— Forms of apparatus have been devised which depend upon this principle. A known measure of the air which is to be tested is enclosed in a vessel, and is exposed to the action of a wire kept glowing by means of an electric current.

The decrease of pressure of the air in the vessel is ultimately measured, and gives a measure of the amount of methane which was present in the air.

The method appears to give results of considerable accuracy in the best forms of apparatus. The apparatus, however, is not sufficiently delicate for modern purposes, and it is scarcely adapted from its nature and construction for general use outside a laboratory.

6. Air containing a Proportion of Inflammable Gas which is not sufficient in Amount to cause it to be Explosive, may be rendered Explosive by adding to it the necessary Measured Quantity of Inflammable Gas.—Apparatus has been devised for applying this principle to the estimation of an amount of inflammable gas in the air which is not in itself explosive. It is only necessary to devise a means of adding more and more inflammable gas to the air in accurately known measure, until the mixture just becomes explosive in contact with a flame.

As has been already shown (p. 2), the minimum proportion of each inflammable gas, which is necessary to make air explosive, is known. Hence by subtracting from this minimum proportion the volume which was added to the air under examination to render it just explosive, the difference will give the percentage of the inflammable gas which was originally present in the air.

Two methods have been devised for carrying out tests on this principle. One involves the use of costly apparatus, the other involves a tedious repetition of experimental trials. Both methods have the disadvantage of requiring a store of the pure inflammable gas, which is being tested for, to be kept in readiness. But they suffer under the still greater disadvantage that they cannot be applied to test air *in situ*. The collection and transport of samples of air involves delay, and is liable to cause danger of change of composition. Under many circumstances also the necessary conditions of the case render the test practically valueless.

7. Testing by Spiring of the Lamp-Flame.—In concluding this summary, a method of testing for gas by the spiring of the lamp-flame should be referred to.

In making these tests the flame is raised until it is on the verge of smoking. When the flame in this condition is brought into the presence of gas, it suffers an elongation. This elongation increases with the quantity of gas present. While the flame is being drawn up in height, it also commences to smoke. My experiments show that an ordinary oil-flame in the safety-lamp became lengthened by about 0.1 inch when it was exposed to air containing 1 per cent. of gas. This was the smallest indication of gas which could be perceived. With the benzoline-flame, spiring was distinctly perceptible in the presence of 0.5 per cent. of gas.

The detection and measurement of these small percentages of gas by the spiring of the flame is, however, not trustworthy. Two per cent. of gas and upwards may be detected with more certainty. But both low and high proportions of gas are more satisfactorily found and measured by suitable flame-cap observations.

Spiring is caused by the supply of oxygen to the flame being diminished. This may arise partly from the admixture of gas with the air, and partly from the removal of oxygen in the neighbourhood of the flame, owing to the combustion of the admixed gas. But this diminution of the supply of oxygen to the flame may be due to various other causes besides the presence of firedamp. Amongst these may be mentioned the following :—

1. Rise of temperature in the air.

2. Admixture of carbonic acid with the air.

3. Obstruction in the gauze by oil or dust, or by soot deposited by the spiring-flame itself.

4. Motion of the lamp, or of the air around the lamp.

5. It must further be remembered that any change in the wick, or in the rate of supply of oil to the wick, after the flame has been set, will alter the sensitiveness of the flame for the test. Such alterations readily occur.

Bearing in mind that the testing-flame must always be set in gas-free air, else its indications by spiring are not absolute, but only relative : further that the test is not a direct test for firedamp, and that its indications are falsified by the presence of carbonic acid, and by many commonly occurring conditions ; the observation of the spiring of the flame cannot be recommended either as an accurate, delicate, or trustworthy method of gas-testing.

General Conclusions.—It will be seen from this cursory review of the principles on which methods of "gas-testing" have been and still are to some extent carried on, that, with the exception of the "flame-cap test," those methods are either untrustworthy or inconvenient, or they are unsuitable to be carried out *in situ*. Any test which cannot be applied *in situ* cannot be universally adopted, since satisfactory methods of making tests at the moment and at the place required are actually available, and meet a general want.

Further, while the practical question of cost cannot be allowed to be weighed, in so important a question as gas-testing, against accuracy and delicacy ; still, if convenient accurate and suitable apparatus can be prepared at moderate cost, this will naturally constitute a recommendation, and will lead to the disuse of the more costly apparatus.

It has always been felt by those who are specially concerned in practical "gas-testing," that the "flame-cap test" possesses the following advantages over other methods which have been already referred to :—

1. The flame-cap test is not appreciably interfered with in its indications by the presence of carbonic acid, or of moisture, within the limits in which these occur in the coal-mine.

2. The presence of inflammable gas or vapour, in addition to methane or marsh-gas, does not appreciably vitiate the indication of the flame-test. The indications

of many other forms of testing-apparatus are rendered erroneous under these circumstances.

3. The variations of the pressure and temperature of the air of the mine, which occur under working conditions, do not appreciably affect the results.

4. The test can be made on the spot where the percentage of gas in the air is to be found.

5. It yields its result at once, without the delay caused by a lengthened experimental process, or by the necessity of calculation or of correction.

6. The apparatus required for the test is simple in character, and cannot easily be put out of order; it is not fragile, and will stand the rough usage to which it may be necessarily subjected in the mine.

7. The method of testing requires no special training or explanation, since it is the one usually employed in the coal-mine.

8. Further, no demand for skill or dexterity is made on the observer beyond that which may be expected of any mine official; and in the better forms of flame-cap apparatus only average eyesight is necessary to perceive and register the indications.

This method of testing has therefore always found favour with those who are concerned in the application of a suitable means of examining air for inflammable gas. And in spite of the confessed lack of delicacy and accuracy of this test when it was applied in its original form, it is hardly surprising that the many ingenious tests founded upon other principles have never been able in practice to compete with the flame-cap test, or to cause its use to be abandoned.

The method of flame-cap testing, however, has not been allowed to remain undeveloped and unimproved. There are now several lamps used for the purpose of " gas-testing," which give results superior to those which were first obtained by the oil-flame of the Davy lamp. And in pro-

portion as acquaintance with and experience in the methods of gas-testing becomes wider, the conviction is arrived at that amongst the various kinds of tests which are available, the "flame-cap test" is still to be *the* test of the immediate future.

Improvements in the flame-cap test have taken place mainly in the following directions :—

1. By the replacement of gauze in the lower part of the safety-lamp by glass.

2. By the introduction of a dead-black background behind the tip of the lamp-flame, so as to throw up the pale flame-cap and to render it more visible.

3. By shielding the direct light of the lamp from the eye, so as to prevent the glare of the illuminating flame from overpowering the pale flame cap.

4. By the admixture with the colza oil of petroleum oil, which prevents the charring of the wick. The reduc- tion of the size of the flame by drawing down the wick is therefore effected with greater precision, and with less danger of extinguishing the flame. The colza oil has even been wholly replaced by light petroleum oil with advantage.

5. By replacing the bright oil-flame by the less luminous flame of alcohol, or by the non-luminous flame of hydrogen.

6. By enabling the test-flame to be set accurately to a standard height, and maintained at this height.

It may be stated generally that the ordinary oil safety- lamp has never been rendered capable of furnishing accurate and delicate tests. The benzene and benzoline lamps, and the best forms of separate alcohol-lamps, have proved more satisfactory as regards delicacy and accuracy; but the separate alcohol-lamp presents the inconvenience of requiring both a lighting and a testing lamp to be carried. None of the forms of single lamp, combining an oil-flame with an alcohol-flame, have proved entirely satisfactory for detecting small proportions of gas.

From the tests of efficiency to be detailed in the next

chapter, it will appear that the lamp which at present presents the greatest convenience, delicacy, and accuracy is the combined hydrogen and oil lamp. There is no doubt that more than 1 per cent. of gas should never be present in the main return air of the coal-mine, and the only lamp which detects and measures with certainty and precision 1 per cent. and fractions of 1 per cent. is the hydrogen-lamp just referred to.

The hydrogen-flame has long been recommended as the most suitable testing-flame, but it is only recently that the application of the flame has been rendered practicable. The flame can now be used alternatively with an oil-flame in one of the best forms of gas-testing lamps.

The hydrogen-flame presents the great advantage of being entirely non-luminous, and it therefore requires no screening from the eye during the observation of the flame-cap; while, on the other hand, it can be at once set to standard height by the adjustment of a valve, since its point is sharp and well-defined. The hydrogen-flame furnishes larger and more visible flame-caps than any other testing-flame.

These advantages of the hydrogen-flame render it so distinctly superior to every other testing-flame, that those who have once become familiar with its use prefer it to all other flames in delicate and accurate testing.

APPENDIX TO CHAPTER II.

GENERAL DESCRIPTION OF SOME FORMS OF GAS-INDICATORS. (Cantor Lectures, Society of Arts, 1894.)

BY FRANK CLOWES, D.SC.

IT has been explained how the miner at first attempted to detect, and ultimately to measure, gas in the air of the coal-mine by means of the flame which he used for lighting purposes. The testing thus effected by flame-cap or by spiring, even when made with the best forms of lighting safety-lamps, is inadequate to detect small proportions of gas. These lamps fail to discover percentages of gas which must not only be detected, but measured, in order to avoid danger in an atmosphere charged with fine coal-dust, and in order to properly regulate and distribute the ventilating current of the coal-mine.

The most successful lighting and testing lamp of this description appears to be the benzoline-lamp of Mr James Ashworth. This lamp, however, cannot be considered to give measurements of gas with any certainty under ordinary conditions, when the gas is present in quantity less than 1 per cent. When it is in its ordinary working condition in the "pit," even 1.5 per cent. may be considered as the minimum amount of gas which can be measured by an ordinary observer.

There is no doubt, however, that the flame-cap test for the detection and measurement of gas is by far the most convenient method for general application, and that it may be made to equal if not to surpass in delicacy and accuracy any of the methods depending upon other principles which have up to the present time been suggested.

In a general review of the accredited methods of gas-testing, it will be convenient to consider these rival methods of gas-testing, before proceeding to describe the more recent improvements in the flame-cap test, which deservedly cause it to remain in favour both on the score of accuracy and of convenience.

METHODS OF GAS-TESTING OTHER THAN THE FLAME-TEST.

Ansell's Diffusion Apparatus.—An apparatus was devised by Ansell (1868), which depended upon the difference in the rate at

which gases which differ in density from air spontaneously mingle with air. As is well known, this process of spontaneous mixture or "diffusion" of gases is a mutual one, each gas penetrating into or mingling with the other.

Air mingled with the light firedamp is lighter than ordinary air. Such a mixture, therefore, possesses the power of diffusing into air at a greater rate than the air diffuses back into it. Accordingly, if the process of "diffusion" takes place through a material of finely porous structure into a closed vessel of air, the pressure of the air within the vessel will necessarily rise.
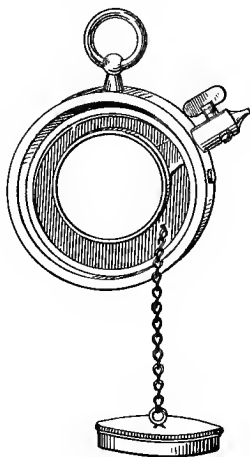
FIG. 1.—DIFFUSION APPARATUS FOR DETECTING AND MEASURING GAS.

Ansell attempted to utilise this fact, and to devise on this principle a small and portable apparatus which would indicate and measure firedamp. The apparatus which has been ultimately adopted consists of a pocket aneroid barometer, the chamber of which is closed at the back by a plate of unglazed or "biscuit" earthenware (Fig. 1). This plate is sufficiently porous to permit the diffusion process between the air inside the aneroid and the external atmosphere to occur, while it prevents the entrance or escape of air by mere mechanical pressure.

The porous plate of the aneroid is protected by a brass cover until the time at which the test is to be made. On the

removal of this cover, the diffusion process commences, and leads to an increase of pressure inside the aneroid, if the external atmosphere is of less density than the air enclosed within the apparatus. This increase of pressure is recorded by the movement of the indicating needle on the dial of the aneroid, and is considered to be an indication of the quantity of firedamp in the air. The tap shown in the figure, or some similar contrivance, serves to release the pressure of air within the instrument.

It is claimed for this apparatus that it also serves for indicating and measuring carbonic acid, or " choke-damp," in air. When this gas is mingled with air, it raises the density of the air. Accordingly, the presence of carbonic acid produces a decrease of pressure within the aneroid, and this is indicated by a movement of the aneroid indicator along the scale in a direction opposite to that which indicates " firedamp."

The opposite effects produced by firedamp and by carbonic acid upon this indicator are one main cause of its indications being untrustworthy under the ordinary conditions of the mine. In all mines there are various sources of carbonic acid gas present. This gas mingles with the air spontaneously, and is also mixed with the air by the ventilating current, and by other mechanical means. Its presence in the air of the mine tends to counteract the effect produced upon the Ansell indicator by firedamp ; and the indication which should be produced by the firedamp present in the air may thus not only be reduced, but may be neutralised, and even reversed.

Air containing 6 per cent. of firedamp is explosive when it is fired from below. The admixture of as much as 15 per cent. of carbonic acid with this explosive mixture does not prevent it from being explosive. Yet this latter mixture would, when tested by the indicator, show only the presence of carbonic acid, and no firedamp would be detected. Air containing 8 per cent. of firedamp and 8 per cent. of carbonic acid is violently explosive when it is fired ; no firedamp would be found by the indicator in such a mixture. Air containing 4 per cent. of coal-gas and 3 per cent. of carbonic acid showed on the indicator only 1.7 per cent. of coal-gas.

While the presence of carbonic acid tends to mask the effect produced by firedamp upon this indicator, water vapour (specific gravity 0.622) being of less density than air, and almost as light as firedamp (0.558), tends, on the other hand, to magnify

the effect. Indeed, water vapour may even be estimated as firedamp. Changes of temperature, which affect the density of the air, are a further serious cause of disturbance ; as much as 4 per cent. of gas was shown in gas-free air merely by heating the air, and a minus indication of 4 per cent. by cooling the air.

Changes of atmospheric pressure must also be carefully allowed for, if the readings are to be of any value. It is further found that when the apparatus is in constant use in the mine, the porous plate becomes clogged with fine dust, and this arrests diffusion, and prevents the indications from being obtained at all.

After pointing out these numerous sources of serious disturbance to the indications of the apparatus when it is used in the mine, it seems scarcely worth while to add that the indications themselves are too small in amount to enable traces of gas to be found, since the presence of 1 per cent. of firedamp in the air produces a pressure record in the apparatus equal to only 0.0086 inch of mercury. It will therefore be seen that the apparatus is not only wanting in accuracy but also in delicacy when it is used in the coal-mine, and that it is untrustworthy, and therefore apt to seriously mislead if its indications are relied upon.

This short description and criticism of the Ansell indicator would have been unnecessary, if its trustworthiness and delicacy were not still relied upon by some who employ it on account of its convenience.

Forbes's Damposcope measures the length of the air column which is necessary to produce acoustic resonance to a musical note of standard pitch. Since the length of this column is dependent upon the density of the air, an experiment made upon the air of the mine gives a means of calculating its density. The indicator therefore affords the same information as the Ansell aneroid does, and the indication of gas which it furnishes is subject to the same sources of disturbance and error. Attempts have been made to apply corrections, by which a more or less correct estimation shall be possible, but it will be seen that the record of firedamp is not direct and immediate, and under not uncommon conditions may be erroneous.

The Hardy Detector depends upon the same principle as the Forbes apparatus ; but instead of measuring the length of

the air-column, which is required to produce a note of a particular pitch, the number of beats per second are counted which result from blowing two precisely similar organ pipes simultaneously. One of these pipes is blown with gas-free air, the other with the air to be tested for gas. The method is subject to the sources of disturbance and error already referred to in connection with the Ansell and the Forbes indicators.

The **Aitken Indicator** depends upon the principle of comparing the temperature of the air, as indicated by a thermometer with a naked bulb, with the temperature shown by a thermometer whose bulb is coated with platinum-black. Both thermometers are exposed side by side to the air of the mine.

The platinum-black induces a slow combustion of any firedamp present in the air. This causes a rise in temperature to be registered by the thermometer with the covered bulb, and the rise of temperature thus noticed, or the difference between the temperature readings of the two thermometers, will increase as the proportion of gas present in the air increases.

This apparatus depends upon the maintenance in unchanged efficiency of the spongy platinum. Unfortunately this substance undergoes rapid deterioration by absorption of moisture and by the deposition of dust upon its surface. The method of testing is therefore not competent to give standard results. It is also very doubtful whether the apparatus is free from danger, since the platinum may reach a red-heat in the presence of a high percentage of gas, and cause the gas to fire or explode.

Liveing's Electrical Indicator.—This apparatus is commonly known as an electrical indicator. It is electrical only in the sense that an electric current is used as a convenient source of heat. The indications are dependent upon the elevation of temperature produced by the combustion of any firedamp present in the air. Instead of registering thermometrically the elevation of temperature, however, as is done by the Aitken indicator, this apparatus records the increase of illuminating power which results from the higher temperature.

In its original form the indicator consists of a small magneto-electric apparatus enclosed in a box. By turning a handle on the outside of the box, an electric current is produced from the apparatus, and this passes through two precisely similar platinum wire spirals, heating them to dull redness.

These wires shine with precisely equal brightness when they are exposed to gas-free air. If, however, one of them is exposed to gas-free air, and the other to air containing firedamp, the heat produced by the combustion of the firedamp upon the surface of the wire causes the one spiral to glow more brightly than the other one.

This difference in brilliancy is easily visible to the eye, even when only a small quantity of gas is present. But in order to increase the precision with which the difference in brilliancy of the wires is noted and measured, the wires are made to illuminate the opposite sloping surfaces of a block, H (Fig. 2), which can be moved by the rod, K, along the graduated scale, L, until the illumination of the surfaces is equal. The position of H upon the scale then indicates at once the percentage of gas present in the air. The adjustment of the block, H, is made, and the scale is read, by looking through a glazed opening, C.
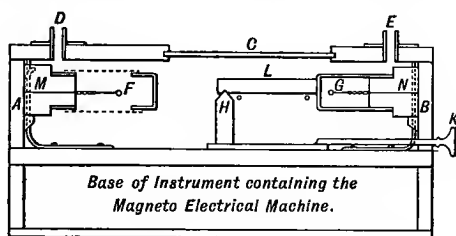
FIG. 2.—SECTIONAL VIEW OF THE LIVEING INDICATOR.

The space in which the spirals and the recording apparatus are enclosed is filled with the air which is to be tested by means of the two openings, D, E, the air being most conveniently drawn through this space by suction from the mouth. The air at once reaches the spiral, F, through the wire-gauze which surrounds it, whilst the spiral, G, is enclosed in a metal tube containing gas-free air, and is therefore never reached by the gas. The light emitted by the spirals passes through glass plates, which close the wire-gauze tube, M, and the metal tube, N, and thus reaches the photometric apparatus. The indicator is shown in use in the mine in Fig. 3.

It is claimed for this indicator that it detects firedamp, and measures its quantity accurately, when the gas is present in percentages ranging from 0.25 upwards, and the satisfaction with

which the indicator has been employed for a time in many coal-mines vouches for the accuracy and delicacy of the principle upon which it rests. Dissatisfaction has, however, been expressed with its weight, and with the fact that it furnishes no light. The apparatus must therefore always be carried together with a safety-lamp which is required for lighting purposes.

Considerable difficulty has also been experienced in obtaining, by means of the magneto-electric apparatus, a current of sufficient steadiness and constancy to furnish satisfactory

Fig. 3.—Method of Using the Liveing Indicator.

readings. The current is sometimes produced of such intensity that the exposed platinum spiral becomes fused and rendered useless. This is particularly likely to occur when much gas is present, and causes the wire to glow brightly. The replacement of a spiral thus rendered useless has hitherto been attended with serious delays.

Complaints are therefore not unnaturally made of the inconvenient method of generating the current, and of the unsatisfactory nature of the current which is produced

It has been further pointed out that as an indicator, to be

used independently of other indicators, it would leave one in serious doubt as to the percentage of gas actually present. The maximum indication which can be given by the instrument will evidently be diminished by the addition to the gaseous mixture which produces it either of more air or more firedamp. Hence when lower readings are obtained on the scale, which would naturally be taken as a proof that less firedamp was present, these readings might be due to an increase, and not to a decrease, in the proportion of firedamp present, and might really be caused by a dangerous deterioration, and not by an improvement of the atmosphere. If the indicator is used, as is commonly the case, conjointly with a safety-lamp, deception of this kind could not easily arise.

Mr James Grundy has, however, recently pointed out a source of inaccuracy which is far more serious, because it cannot at present be avoided. He has shown that while for several successive tests the indications of the apparatus both for high and for low percentages are all that can be desired, the indications soon begin to alter materially. This is due to the wire spiral which is exposed to gas undergoing a marked change in its electrical resistance after it has been used for a time. This change necessitates the zero of the scale being set afresh in air free from gas ; and such air cannot always be easily obtained underground. In some cases this change was so considerable, even during one round of testing in the coal-mine, that the scale could not be readjusted truly to the zero mark at all, even in fresh air.

This change in the wire cannot be foreseen with certainty ; it is also difficult or impossible of correction, as has been stated, and the possibility of its occurrence leaves one in a condition of uncertainty as to value of a test when it has been made.

It has also been pointed out that any electrical apparatus, if used in explosive atmospheres, may cause danger by sparking.

Apparatus, depending upon the Change of Pressure caused by Burning the Gas present in an Enclosed Volume of Air, has been described by several inventors. The complete combustion of the firedamp present in the air produces a decrease in volume approximately equal to twice that of the firedamp present. The decrease of volume may be measured as such, but it is usually indicated by the decrease of pressure which it causes in a closed vessel, connected with a suitable gauge.

The names of Maurice, Coquillion, and Le Châtelier are associated with forms of apparatus depending upon the above principle. In all these forms of apparatus the firedamp, which is present in the sample of air contained in the closed vessel, is burnt by maintaining a metal wire at a red-heat in the air for about thirty seconds. The incandescence of the wire is produced by the passage of an electric current.

In the Coquillion apparatus (1887) the indications are rendered inaccurate by the exposure of the air containing the products of combustion to water. The carbonic acid produced by the combustion of the firedamp is soluble in this liquid, and may be
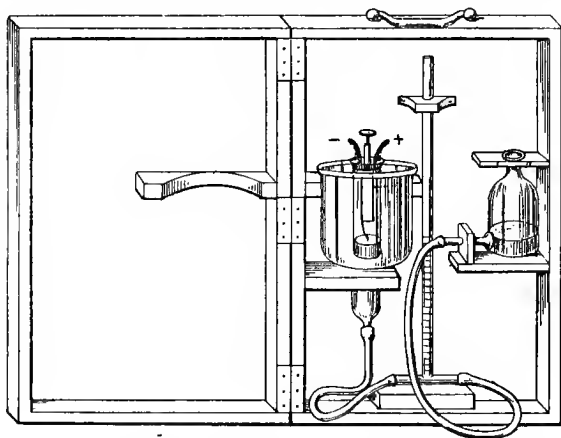
FIG. 4.—THE CHATELIER INDICATOR.

more or less completely dissolved, according to the proportion present, and its exposure to the water. This introduces an uncertainty in the results.

Le Châtelier avoids this source of error by substituting mercury for water (Fig. 4). He also hastens the process of measurement by surrounding the test-vessel with a water-jacket, which quickly cools the heated products of combustion, and therefore lessens the interval of waiting before the true pressure-reading can be taken. The tests made with this apparatus appear to be of a satisfactory nature, and the apparatus is an improvement on those of Maurice and of Coquillion. The presence of 1 per cent.

of gas is indicated by a change of pressure, amounting to 0.5 inch of mercury.

It must be remembered, however, that these forms of apparatus are all of such a nature as to be suited rather for being handled by a skilled manipulator in a laboratory than for use underground. They have to be carried, together with a safety-lamp, and with an apparatus for producing an electric current. On account of these objections, of their fragile character, and of the ease with which they may be put out of order in the coal-mine, they would naturally give way to more simple and portable apparatus which gives equally satisfactory results, when the tests are to be carried out in the pit itself.

Other Forms of Apparatus ascertain the Amount of Inflammable Gas or of Air, which must be added to the Air containing Firedamp, to bring the sample to the Condition in which it just fires in contact with a Flame. Manifestly, the volume of inflammable gas which must be added to mine-air will be less in proportion as the quantity of firedamp already present is larger.

The simplest form of apparatus devised for this purpose is the eudiometer of Le Châtelier. It consists of a glass tube open at its larger end (Fig. 5), the upper part of which is narrow and is divided by graduations. Each graduation marks 1,000th part of the capacity of the tube when it is filled to a mark near its larger end.

If the sample of air to be tested is not inflammable, the tube is filled with water, and inflammable gas is passed up, the number of graduations which it fills in the tube being read off. The tube is then filled to the standard mark with the air under examination. The mouth of the tube is closed with the thumb, and the tube is removed from the water. Its gaseous contents are then well mixed by being shaken up with the water in the tube, and a light is brought to the mouth of the tube in a darkened room. If the mixture kindles, the test must be repeated with the admixture of a known

FIG. 5.

smaller proportion of inflammable gas. These experiments are repeated until a minimum addition of the gas necessary to produce kindling by the flame has been reached. This minimum volume having been ascertained, a simple mathematical formula gives the proportion of firedamp originally present in the sample of air.

If the sample of air to be tested is already inflammable, a similar procedure is adopted, but in this case the addition of air must be substituted for that of inflammable gas. It has been recommended to use coal-gas instead of firedamp in adding inflammable gas, as a matter of convenience.

This apparatus is said to give satisfactory results. It is manifestly slow in yielding a measurement of the percentage of gas present in the air. The results are of doubtful accuracy if coal-gas of variable composition is employed instead of methane, while the process becomes troublesome if pure methane has to be prepared.

The apparatus may be suitable for use in a darkened labora-
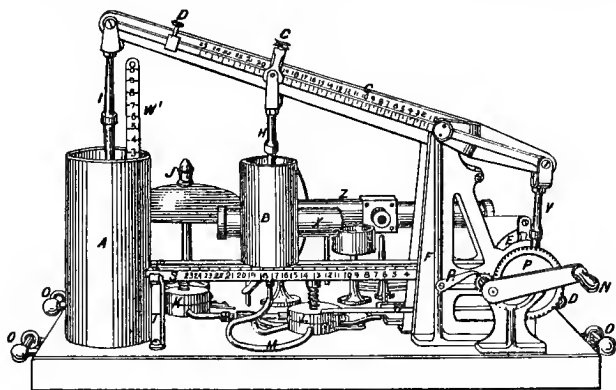
FIG. 6.—SHAW'S INDICATOR (Side View).

tory above ground; it certainly is altogether unsuitable for yielding prompt tests in the coal mine: the use of the naked flame alone would condemn it as unsafe. Where samples of air can be transported and tested it might be adopted, but this is scarcely the requirement of the present day.

Shaw's Indicator depends upon precisely the same principle as the above apparatus. By ingeniously arranged mechanical means, a stream of the air which is to be tested is thoroughly mingled with a known proportion either of inflammable gas or of air, and is then passed over a flame. The proportions in which this mixture is made can be varied at will, and can be maintained unchanged as long as may be desired. The proportions are

adjusted until the mixture is just brought to the lowest limit of kindling at the flame. The kindling is indicated automatically by the sounding of a bell.

The lowest proportion of the inflammable gas which can be kindled when mixed with air is first determined. The operator is then in a position, after reading off the proportion in which

FIG. 7.—SHAW'S INDICATOR (Top View).

he has actually mingled his test-sample with additional air or gas, to calculate the proportion of this gas present in the sample which he is testing.

The general construction of the apparatus is shown in Figs. 6 and 7. A, B represent two cylinders containing air-tight pistons moved by the rods I, H. The rods themselves are moved by the beam which oscillates on the pivot V, and the oscillatory move-

ment of the beam is maintained by turning the winch N, which, by gearing, gives a vertical movement to the connecting-rod v.

The movements of the pistons force the two gases, which are to be mingled, from the cylinders A and B. The exact proportions of these gases is controlled by the position of the movable cylinder B and the piston rod H, on the fixed rod S and the movable beam respectively. The gases pass through a mixer, X, to a cylinder, Z, and if the mixture is explosive, it is fired by coming into contact with a small flame. The firing of the mixture releases a striker against the bell (J), and the sound of the bell indicates that the mixture is explosive.

It is obvious that by this means the cylinders can be made to pump air and a combustible gas, and the proportions in the mixture can be gradually varied until the mixture is just explosive. In this way the explosive proportions of air and gas may be determined. So also air containing some combustible gas may be mingled with a known additional amount of gas or of air, until it becomes explosive.

The apparatus, when it is working in its normal condition, appears to give indications of considerable accuracy and delicacy. It is credited with detecting and measuring firedamp down to the lower limit of 0.1 per cent., a proportion which is easily detectible by means of the hydrogen-flame.

It must, however, be understood that the apparatus is large and heavy, and is wholly unsuited to be taken underground. The samples of air to be tested must be brought to it. This collection, storage, and transport of large samples of air is attended with much inconvenience and delay, and with risk of the sample undergoing change of composition before it is subjected to the test. The apparatus itself also is of complicated construction, and requires constant attention to maintain it in normal and satisfactory condition. Further, it is very costly, and its nature necessitates its price being high.

These various objections to the general use of the Shaw indicator would have less weight if other cheap and equally accurate and delicate indicators did not exist. Other indicators, however, are now in use, which can be applied to testing samples of air brought from the pit. These have, moreover, the great advantage of being simple in use and easily portable, so that they can be applied to test for the gas in the pit itself. They accordingly give an immediate record of the

proportion of gas present, on the spot, and without incurring any delay or risk of change in composition, such as is involved in collecting samples and transporting them to a laboratory on the surface of the ground. These simpler forms of apparatus also dispense with the troublesome necessity of maintaining a supply of methane-gas, and with the uncertainty of the indications which necessarily results from the substitution for methane of coal-gas of variable composition.

General Conclusions.—It will be seen, from this brief review of the forms of gas-testing apparatus, which are not flame-tests, that some are practically laboratory methods only, and cannot be carried out with convenience and safety in the mine itself; whilst others are inconvenient, and others again give indications which are open to doubt, or are entirely untrustworthy.
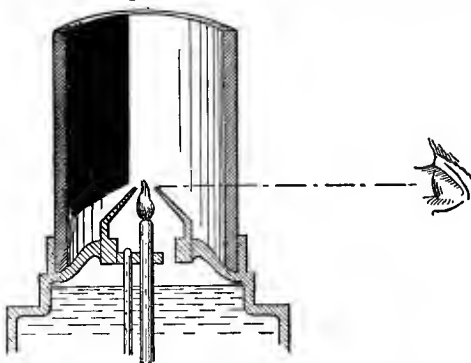
FIG. 8.— IMPROVED OIL-FLAME TEST.

Flame-tests have, on the other hand, now undergone a satisfactory development, which renders them available in cheap and convenient forms of apparatus. These can now be employed in the mine itself with safety, and can furnish indications, which are at least equal in accuracy and delicacy to those furnished by the most trustworthy forms of apparatus already referred to.

IMPROVEMENTS IN FLAME-CAP APPARATUS.

MM. Mallard et Le Châtelier remedied, in 1881, some of the defects of the oil-flame, as it is ordinarily applied to gas-testing. In the lamp introduced by these gentlemen, the reduced flame was concealed from the eye by metal screens (Fig. 8), and it

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could be roughly brought to standard height by drawing down the wick until the tip of the flame just reached the upper edge of these screens. The cap was also rendered visible by observing it through glass instead of through gauze, and by placing behind it a dead-black background.

This lamp accordingly enabled lower percentages of gas to be detected than were discoverable by the Davy lamp. But it still possessed the disadvantage of employing an oil-flame; and this flame cannot be considered a standard flame, since it is subject to serious and rapid alterations in size. The flame was also too small to give distinct and easily visible caps in the presence of small proportions of gas. Complaint was further made that the flame, when raised to its full height for illuminating purposes, lost much of its lighting power, owing to the obstruction offered by the screens.

James Ashworth, working on somewhat the same plan, also introduced in 1891, a lamp which burns benzoline. This prevents the serious charring of the wick which occurs when oil is used. The reduced benzoline-flame is superior to the oil-flame for testing purposes. It maintains its height more satisfactorily after having been adjusted, it possesses less luminosity, and when in use it is shielded from the eye by a screen, which also serves for setting the flame to uniform height.

The caps are observed through glass against a roughened non-reflective background; and although the caps are small, and with low proportions of gas are apt to be confounded with the halo always visible over the benzoline-flame, they are undoubtedly recognisable and measurable when 1.5 per cent. of gas or upwards is present.

The flame is inconveniently sensitive to sudden changes of air pressure, to rapid movement of the lamp, and to rise of temperature, and in its reduced state is liable to extinction from these causes.

MM. Mallard et Le Châtelier, in 1881, proposed another plan for increasing the delicacy and accuracy of the flame-cap test for gas. Recognising that one of the principal disadvantages hitherto attaching to this test arose from the necessity of employing a very small flame, reduced in size in order that it might not be luminous, they suggested the adoption of a flame which was only slightly luminous, or even non-luminous, even

when it was of large dimensions. The flames which naturally occurred to them were those of alcohol and of hydrogen.

They found that with a large alcohol-flame o.5 per cent. of firedamp could be detected, while a hydrogen-flame enabled o.25 per cent. of the gas to be readily found. These gentlemen proposed to burn the testing-flame in a separate safety-lamp, which would be carried together with the illuminating oil-lamp. Since the hydrogen-flame proved itself to be superior to the alcohol-flame, they attempted to devise a means for the chemical generation of hydrogen-gas in the oil-reservoir of a safety-lamp, intending to burn this gas in a regulated stream from a jet fixed within the lamp and connected with the reservoir. This attempt ended in failure ; the process of generating the gas was troublesome and unpractical, and the regulation of the size of the flame was found to be impossible.

Friedrich Pieler, in 1883, described an arrangement by which a hydrogen-flame of more or less standard dimensions might be produced from a chemical generator, and might be used above-ground to test samples of gas brought up from the mine. This apparatus was not adapted to the ordinary necessities of gas-testing in the mine, and does not appear to have come into use.

But, failing to adapt the hydrogen-flame to an ordinary safety-lamp, Pieler devised a large gauze-lamp, similar in character to a Davy lamp, in which alcohol, instead of oil, was burnt from the reservoir by means of a circular wick. A large pale but somewhat luminous flame was thus obtained, which was concealed from the eye by a circular conical metal screen (see Fig. 9), and was set to standard height by bringing its top to a level with the top of the screen.

The large flame of the Pieler lamp gives caps of much greater dimensions than those which are furnished by the ordinary flames employed for gas-testing.

The lamp in its original form was, however, far from being safe for use in the coal-mine. The flame of gas burning within the gauze could be blown through the gauze, and could also make the gauze red-hot, and thus lead to firing of gas in the air around. This danger has been removed by " bonnetting " the lamp, or surrounding the gauze by a metal cylinder. The observation of the caps is made through a window in the bonnet. The use of the window, after the glass has been dimmed by the

burning of the lamp-flame for a time, much impairs the visibility of the smaller and fainter caps.

Another cause of trouble and dang er arises from the heating of the alcohol reservoir by the com bustion of gas within the
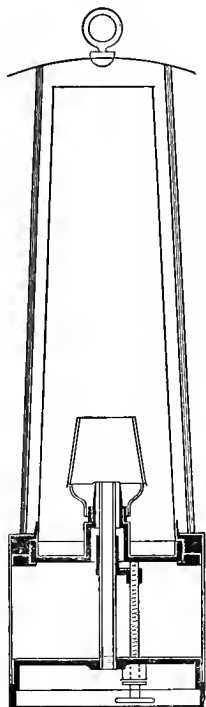

FIG. 9.
SECTION OF PIELER LAMP.
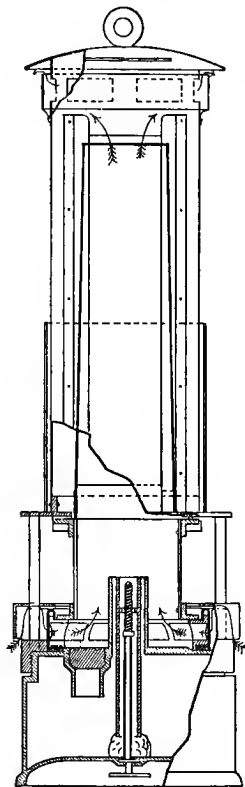
FIG. 10.
SECTION OF CHESNEAU LAMP.

g auze of the lamp. This causes the alcohol ultimately to boil, and leads to the production of a large and dangerous flame of burning alcohol vapour. This property of the lamp renders it impos sible to take it into any part of the mine, where morc than 2 or 3 per cent. of gas may be present.

In any case, the lamp cannot be used in the mine, unless it is accompanied by an ordinary lighting safety-lamp, since the alcohol-flame itself does not serve for illumination. The lighting-lamp, accordingly, is employed to test for the higher proportions of gas down to 3 per cent.; and the Pieler lamp, which cannot indicate more than 1.75 per cent. of gas by the flame-cap, is employed only for the lower percentages. It will be noted that there is a gap thus left between the measurements given by the two lamps.

The Pieler lamp has been used in many mines, where the manager undertakes the wise, if not necessary, precaution of systematically examining the air for traces of gas. It is undoubtedly more delicate and accurate in its indications than the oil-lamp, but it falls, in many respects, short of the standard to be desired. Careful experiments undertaken with this lamp have shown that it possesses the following disadvantages :—

1. Although arrangements are made to bring the alcohol-flame to standard height, it is impossible to adjust the height with any certainty, since the tip of the flame is of a hazy and indefinite character. Any slight variation in the strength of the alcohol, or in the adjustment of the height of this large alcohol-flame, produces considerable effect upon the height of the flame-cap and the consequent measurement of the gas. Thus, the following differences in cap-height were noted, with varied height of test-flame :—

VARIATION OF HEIGHT OF CAP WITH HEIGHT OF
TEST-FLAME.

Percentage of Gas.	Test-flame 0.4 inch.	Test-flame 0.6 inch.
1 per cent. of gas.	1 inch cap.	2 inch cap.
0.5 ,, ,,	0.9 ,,	1.5 ,,

2. The hazy tip of the flame in gas-free air corresponds almost precisely with the cap produced above the flame by the presence of 0.25 per cent. of gas ; hence this proportion of gas cannot be detected and measured with any certainty.

3. The serious obstruction offered by the gauze, and by the window in the bonnet when it is slightly soiled, prevent the fainter caps from being seen at all. This effect is increased by

the unsuitability of the gauze as a background to the caps. Thus a cap which was 140 millimetres in height over the naked flame was reduced to 47 millimetres when it was seen through the gauze; that is, the indication of 1 per cent. of gas was reduced to that for 0.5 per cent. This is probably the reason why the cap-heights actually seen do not at all agree with the heights shown on the scale-glass.

4. The range of testing with the alcohol-flame is very limited, and becomes still more limited by the peculiarities of the lamp already referred to. Another indicator must therefore always be at hand to supplement the Pieler lamp.

5. The inconvenience due to the necessity of carrying a second lamp together with the Pieler lamp, and the fact that it becomes strongly heated if exposed to even a moderate amount of gas, so as to lead to danger and to unfit it for further gas-testing for a long time, are also serious defects in this lamp.

M. Chesneau, in 1892, introduced another form of lamp, burning a large alcohol-flame, for gas-testing. The lamp is of the Fumat pattern, and takes its air-feed from below the burner (Fig. 10). The upper part of the lamp is isolated from the reservoir, so as to avoid the dangerous heating of the alcohol which occurs in the Pieler lamp. The construction of the lamp is further stated to provide for the total extinction of all flame within the lamp, when it is exposed to dangerous proportions of gas.

One of the principal advantages, however, which is claimed for this lamp is the introduction of a copper-salt into the alcohol of the reservoir ; this leads to the flame and the caps being coloured, and thus renders them more visible. The salt originally used for this purpose was copper chloride. But both this salt, and the acid which must be used with it, corrode the reservoir and wick-tube, and lead to the formation of a deposit of cuprous chloride, which rapidly chokes the wick. Hence copper nitrate, together with some ethylene chloride, has recently been dissolved in the alcohol in place of the copper chloride. This modification is stated to remove the serious inconvenience arising from the use of the copper chloride.

Experiments made with this lamp show :—

1. That the flame-caps yielded by less than 1 per cent. of gas are much more distinctly seen than they are in the Pieler lamp, and they agree with the scale on the lamp.

2. That caps yielded by more than 1 per cent. of gas are hazy and difficult to measure, and are in no way superior to those which are seen in the Pieler lamp.

3. That the upper part of the alcohol-flame is not more sharply defined than that in the Pieler lamp ; a cap or halo is always visible over the flame even in gas-free air, and the flame cannot be set to height with the precision necessary to yield standard results.
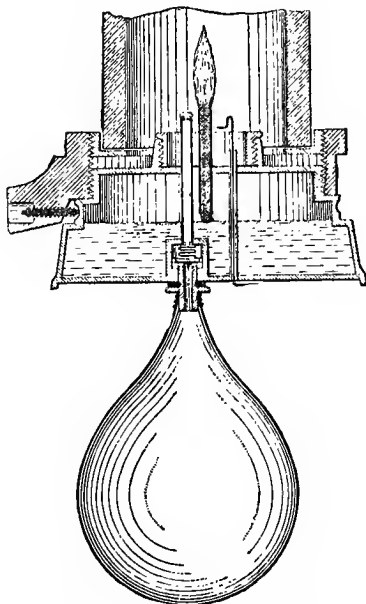
FIG. 11.—THE GARFORTH COLLECTOR.

4. That the scale of the lamp, being on the outside, can only be read by means of another lamp.

5. It may be added that the lamp is heavy and of complex construction, and that the array of precautions and directions which appear to require attention when this lamp is used is of formidable dimensions.

Collection of a Small Sample of Air for the Flame-Test.

It is often a matter of difficulty, and even of impossibility, to introduce a safety-lamp into air which has to be tested for gas. Or, at least, it is impossible to look for a flame-cap in the lamp, owing to the lamp being beyond the level of the eye. Further, the introduction of the lamp into air containing much gas leads to the extinction of the flame, and one naturally hesitates to introduce the lamp for testing purposes with the conviction that all the inconveniences due to loss of flame will be the result.

In such cases, when only high percentages of gas have to be looked for, the Garforth Collector is useful (Fig. 11). It consists of a small hollow rubber ball provided with an open metal nozzle. The small ball is squeezed within the hand until the air is removed from the interior, and is then allowed to resume its shape while the nozzle is surrounded by the air to be tested. The nozzle is then inserted into a tube, protected by gauze and a valve, which passes through the oil vessel of the lamp, and the sample of air is expelled over the lamp-flame. Any appearance of burning gas is noted. This arrangement serves to detect only comparatively large proportions of gas, and does not give any measure of the percentage present.

CHAPTER III.

EXAMINATION OF THE ACCURACY AND DELICACY OF DIFFERENT FLAME-TESTS.

INTRODUCTORY.

IT has been shown in the preceding chapter that there are good reasons why the use of the flame-cap test has always been preferred to all other methods of gas-testing. These reasons account for the fact that inflammable gas or vapour in the air is still generally detected and measured by the flame-cap test to the exclusion of many other methods which depend upon different principles.

The flame-cap test itself, however, is applied in various ways, and different test-flames have been proposed for use. In order to compare the different methods of flame-cap testing, and to ascertain their relative merits as regards delicacy and accuracy, it is necessary to be able to observe, under favourable and trustworthy conditions, the flame-caps which are yielded by known percentages of "gas" in the air.

Apparatus for the careful observation of flame-caps has been employed by different experimenters. The process has, however, always involved the preparation of a large amount of each gaseous mixture into which the flame was to be introduced. Trials with such apparatus indicated that it was unnecessarily costly and complicated, and that it frequently necessitated the test-flame being burnt under conditions which did not correspond sufficiently closely to those under which tests would ordinarily be made. Hence doubt was felt as to the correspondence of the experimental flame-caps with those which would be obtained in practice.

The Test-Chamber.

Accordingly a new form of apparatus was devised for the examination of the flame-tests. This apparatus has been named the "test-chamber." It enables a flame to be examined in different mixtures of air and inflammable gas in which the percentage of gas is accurately known.

The Test-Chamber (Fig. 12) consists of a wooden gas-tight box of 100 litres capacity. It is provided with a
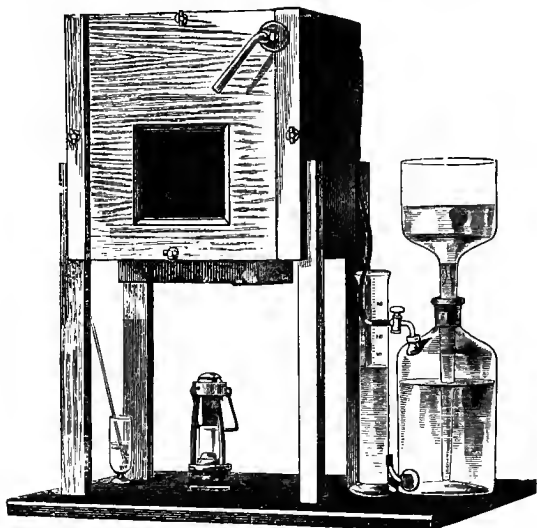
Fig. 12.—The Test-Chamber.

plate-glass window in front for the observation of a flame burning in the interior. There are inlet tubes, one at the top of the chamber, the other at the bottom. These serve respectively for the admission of a measured volume of inflammable gas, and for the escape of the air displaced by this gas. The tubes are closed when not in use. A large thin wooden flap can be swung inside the chamber after the measured volume of gas has been introduced, so as to pro-

duce in a few seconds an intimate mixture of the gas with the air of the chamber.

A large opening is provided in the bottom of the chamber for the purpose of introducing the safety-lamp which is to be tested. There is a corresponding opening in the top of the chamber to assist in replacing the atmosphere within the chamber with pure air after the test is completed. Arrangements are made for closing these openings air-tight. Smaller openings are made in the bottom of the chamber to serve for introducing flame-jets, and for adjusting the safety-lamp flames by means of the prickers.

The test-chamber is blackened inside, and is used in a room from which daylight is excluded. If the room is lighted by gas or oil, the flames should be turned low, or the eyes should be shielded from their light by means of a black cloth, while observations are being made in the chamber. The cloth is thrown over the head and over the top and sides of the front of the chamber, just as is done during the focussing of a photographic camera.

In addition to the above precautions for excluding external light, and thus rendering the flame-caps more easily visible, it is necessary, when accurate observations of small and pale caps are to be made, that the eyes should have been shielded from daylight or powerful artificial light for about twenty minutes before the observations are commenced, in order that due sensitiveness shall be obtained.

It will be seen that the general arrangements of the test-chamber enable mixtures of air with known percentages of gas to be quickly prepared with little expenditure of gas. They further render possible an accurate observation and measurement of the flame-caps produced over flames which have been introduced into this mixture in a darkened room. For a full account of the test-chamber, see page 102.

Influence of Carbonic Acid on the Flame-Cap.

By examination of the flame-cap in the presence of carbonic acid, it has been proved that this gas, even when

present to the extent of 5 per cent., does not affect the cap.

INFLUENCE OF SIZE OF TEST-FLAME ON FLAME-CAP.

Experiments made with a "naked" flame, which was burning freely in the chamber, and was not surrounded by the lamp-glass and the safety-lamp, showed that the height of the cap seen over the flame in air containing a known percentage of gas increased as the height of the test-flame was augmented. The cap-height, however, was found to increase at a more rapid rate than the flame-height did, and no simple relation seemed to exist between these heights.

It is therefore evident that if the percentage of gas present in the air is to be accurately judged by the height of the cap seen over the flame, the test-flame must always possess, at the moment of observation of the cap, an absolutely fixed and uniform standard height. If the flame falls, the cap will be too small ; if it rises, the cap will be too high, and the percentage of gas inferred to be present will vary appreciably from the percentage actually contained in the air.

POSSIBILITY OF ADJUSTING VARIOUS TESTING-FLAMES TO STANDARD HEIGHT.

Since the adjustment of the test-flame to standard height, and its maintenance in this condition, are absolutely necessary in measuring gas, experiments were made with the various flames at present used in gas-testing with the object of ascertaining their suitability to serve as standard flames, which would give trustworthy and invariable cap measurements at all times for corresponding percentages of gas. The general results arrived at are stated below. Fuller details are given on page 112.

The Colza-Oil Flame of a freshly trimmed ordinary safety-lamp was reduced in height by lowering the wick by the "pricker." The upper edge of the flame was sharply defined, and could therefore be brought to a fixed level with

precision. The adjustment of the flame, however, was found to be difficult or impossible when the wick had become charred by allowing the flame to burn for some time previously to the adjustment. Further, this flame could not be retained with any certainty at the standard height, and if it had been made sufficiently small to almost abolish its luminosity, so as to be able to observe a small percentage of gas, the flame rapidly fell in height until it was ultimately extinguished.

The Colza-Petroleum Flame. — It is now very common to burn a mixture of colza and petroleum oils in safety-lamps. The presence of the petroleum oil tends to lessen the charring of the wick, and to improve the illuminating power of the flame. The introduction of the petroleum was found to produce a slight cap-like appearance on the summit of the flame. This fact, together with the tendency of the reduced flame to rapidly fall in height, and to become extinguished, rendered the flame unsuitable for detecting small percentages of gas.

It is noteworthy, however, that when higher percentages of gas were observed by a reduced oil-flame, the flame was better maintained, and did not suffer extinction. This is probably due to the heat produced by the large cap.

The Alcohol-Flame could never be set with any certainty and precision to standard height. The tip of this flame was always pale and hazy, gradually fading away until it was lost to view. It was therefore impossible to decide upon any upper margin which might be brought on a level with the fixed standard. The proposal to colour the flame by a copper salt, which is referred to elsewhere, is found not to materially improve the flame in this respect.

A further difficulty arose from the fact that this indefinite top of the flame was indistinguishable from a small " flamecap." In the case of an alcohol-flame it was therefore impossible to distinguish between the appearances of the flame

when it was burning in air free from gas, and when it was burning in air containing a small percentage of gas.

The flame further showed the disadvantage of varying in size, a peculiarity of all wick-fed flames. Its luminosity was too great to permit of its being viewed by the eye while observing the cap.

The Benzoline-Flame, when reduced in size for gas-testing, could not be set to standard size with precision, since its tip was hazy and indefinite. It showed a distinct " cap" in air free from gas, and it was subject to sudden and rapid variations from its standard size.

The Hydrogen-Flame did not under any conditions furnish a hazy or cap-like summit. Only when its dimensions were considerable did a slender tail or prolongation upwards of the flame appear. The junction of this with the flame was a sharply defined point, and no resemblance to a cap existed. The small flame, such as is used in gas-testing, obtained from a supply of ordinary hydrogen gas, gave practically no light, and was only visible in a darkened room. Its upper edge was absolutely sharp and well defined, presenting no tail or cap, and could be brought to the standard mark with certainty and precision.

The flame, being fed from a supply of gas under pressure, was not subject to the rapid fluctuations of size which are peculiar to wick-fed flames, and was found to be easily retained at standard height, and to be perfectly manageable.

The only inconvenience in the use of the hydrogen-flame arose from a deposition of moisture on the interior of the lamp-glass when the flame was burnt for a long time in a safety-lamp which was exposed to a powerful draught of cold air. This was preventible by shielding the lamp-glass from the direct action of the air-current. It has recently been entirely prevented by substituting a surface of talc for one of glass.

GENERAL OBSERVATIONS ON THE VARIOUS TEST-FLAMES
AND ON THE MEASUREMENT OF THE CAP-HEIGHTS
OVER THEM.

A series of careful measurements were then made of the heights of the caps which were produced over the various testing-flames in different safety-lamps. The methods of measuring the caps, together with results obtained, are stated on page 110.

The caps were measured when the flames were exposed in the test-chamber to air containing known percentages of methane (marsh-gas), of coal-gas, and of water gas, which were increased to 6 per cent., the lower explosive proportion for coal-gas and methane. The measurements were made while the flames were burning within the safety-lamp. The details of the process of measurement and of the results obtained will be found in Chapter V.

The following general conclusions were drawn from these measurements.

The Oil-Flame.—This flame was obtained from an ordinary flat cotton-wick, which was fed with a mixture, in equal measures, of colza and petroleum oils. The upper edge of the wick was cut level, and was carefully cleansed from hard crusted matter, produced by charring, before the experiments were started.

In one series of experiments the wick was drawn down by the " pricker " in air free from gas, until the flame was made as small and non-luminous as possible.

This flame was found to rapidly diminish in size, unless gas was present in the proportion of 4 per cent. or upwards.

The cap measurements obtained over the oil-flame were accordingly found to be fairly satisfactory only when over 3 per cent. of gas was present ; but with lower percentages it was extremely difficult to obtain any constant reading or even to prevent the flame from suffering extinction.

It may be stated generally that the cap measurements over the reduced oil-flame were satisfactory when the gas present in the air amounted to from 4 to 6 per cent. Lower proportions were either not indicated at all, or the indications were too variable to be trusted.

Another series of observations with the oil-flame was made by so adjusting the height of the wick, *in the presence of the gas*, that the cap had a maximum height. This would often be a convenient method of procedure in practice, when it was difficult to secure the presence of gas-free air, in which the flame could be adjusted before testing.

The caps thus obtained were naturally longer than those yielded by the previous method ; but the range of possible testing became limited on account of the larger cap entering the top of the lamp when 6 per cent. of gas was present. The height of the cap could not then be measured against a scale.

The Benzoline-Flame.—The benzoline-flame possesses, in common with the oil-flame, the advantage that it serves, when of full size, for lighting, and when reduced in height, for gas-testing. The indefiniteness of the tip of the reduced flame rendered this flame unsuitable for estimating with certainty proportions of gas amounting to less than 1 per cent. The caps, however, served to indicate percentages between 1.5 and 6, and with these proportions of gas the caps were clearly seen.

The difficulties in the use of the flame arose from its want of steadiness at standard height when the lamp was hot, giving rise to variations in cap-height for the same percentage of gas. This reduced flame also possessed some luminosity, which hindered the perception of the cap. Further, there was always a suspicion that the vapour from the benzoline, which itself gives a cap over the flame, might escape into the lamp, or into the air around the lamp, and disturb the indications which were considered to be due to the presence of gas alone.

The Large Alcohol-Flame.—This flame has been always used in a large separate gauze safety-lamp, which is applicable only to the detection of small percentages of gas. The feebly luminous character of the flame, and the necessity of making higher tests, entail the inconvenience of carrying a second lamp for lighting and testing purposes in the coal-mine. Not only must both lamps be carried, but both must also be kept constantly burning.

The large alcohol-flame is the largest gas-testing flame in use. Its height is no less than ten times as great as the reduced flames of oil and of benzoline, and three times the height of the standard hydrogen-flame. Since the height of the cap increases rapidly with the increase in size of the testing-flame, the caps over this alcohol-flame are of extraordinary dimensions. Owing, however, to the fact that the large alcohol-flame is always somewhat luminous, and that the caps have to be observed through fine metal gauze, as well as through the soiled glass window in the "bonnet," the visibility of these caps is not by any means proportional to their large dimensions. In fact, the much smaller caps over the hydrogen-flame are decidedly more visible than the comparatively large caps over this alcohol-flame.

As has been already stated, the hazy and indefinite nature of the tip of this alcohol test-flame prevent it from being adjusted with precision to its standard height. This seriously interferes with the standard height of the caps, and with the accuracy with which gas is estimated. Further, the cap-like appearance over the large flame, in air free from gas, is easily mistaken for the cap actually produced by the presence of a small percentage of gas.

No unmistakable detection of a cap was possible when less than 0.5 per cent. of gas was present in the air, and the large caps became immeasurable when somewhat less than 2 per cent. of gas was present. It will be understood that the caps given by intermediate percentages were not of a very definite height, owing to the uncertainty in the adjustment of the flame to standard height.

D

The volatile nature of alcohol always leads to a fear of its vapour mixing with the air in and around the heated lamp and producing a cap, which increases the cap due to the presence of gas. It has also been held that the liability of the alcohol to boil in the heated lamp introduces a source of error as well as of danger.

Variations of the quality and strength of the alcohol were found to produce considerable variations in the cap indications.

An attempt has been made to render possible the accurate adjustment of the large alcohol-flame to standard height, and thus to obtain standard caps, by colouring the flame and the cap. For this purpose a copper-salt has been introduced into the alcohol (p. 38). Experiments with this coloured flame showed that it could not be adjusted to standard height with greater precision than was possible with the uncoloured flame. It was further found that a halo or cap was visible over the flame in gas-free air, and that while the caps yielded by proportions of gas less in amount than 1 per cent. were distinctly seen, caps corresponding to more than 1 per cent. were as hazy and difficult to measure as those seen over the uncoloured flame.

It may be added that the complications in the construction of this newer form of lamp with the coloured flame, which were considered necessary to add to its safety, add considerably to its weight, and to the difficulty of cleaning it. The use of the copper-salt also adds to the difficulty of keeping the lamp in working order.

The Small Alcohol-Flame.—Several attempts have been made in this country and on the Continent to reduce the dimensions of the alcohol testing-flame. The advantage which was anticipated was that the flame might be intro-duced into an ordinary oil safety-lamp, and possibly even as an alternative flame, the oil-flame being used in the lamp for lighting purposes, and the alcohol-flame being exchanged for the oil-flame for the purpose of gas-testing.

The small alcohol-flame possesses all the disadvantages presented by the larger alcohol-flame, together with additional ones peculiar to itself. It is very easily extinguished by movement of the lamp or of the air and by carbonic acid. It cannot be set to standard height with any accuracy, or applied to the detection of small percentages of gas, since it always shows a hazy and cap-like tip. Further, it possesses a considerable degree of luminosity. The large alcohol-flame already referred to is surrounded by a shield on all sides, which minimises the interference due to its luminosity. The smaller flame, when used in an oil-lamp, is not usually thus completely shielded, and its light diffused through the lamp altogether prevents the perception of small or pale caps.

In a series of careful observations of the small alcohol-flame in a safety-lamp, it was found that the flame varied in character at different times. On one occasion it was impossible with the flame unshielded from the eye to see and measure a cap with any certainty until the proportion of gas in the air reached 1.75 per cent. On another occasion, when the flame was shielded in front, 1.5 per cent. was measured. On another occasion a pale but not measurable cap was seen with 0.75 per cent. of gas ; in this case the flame was in its best condition, and was observed by most keen and sensitive eyes. The indications appear therefore to be variable in character ; but on the average not appreciably more delicate than the much simpler benzoline-lamp, and not notably superior to a good oil-lamp used under the best conditions.

The small alcohol-flame is easily "lost," and during the attempt to exchange the oil-flame for the alcohol-flame, and *vice versâ*, the loss of the flame is not unfrequently the result ; whilst the kindling of the alcohol wick by the oil-flame is often an impossibility.

The Hydrogen-Flame.—It will be seen from the above summary of results which have been arrived at by observations many times repeated, and have been confirmed by

different observers, that there remains much room for improvement in the methods of flame-testing already described. The gas-testing safety-lamps using oil, petroleum, or alcohol, are wanting in accuracy, in delicacy, and sometimes in safety.

It was resolved, therefore, to make further experiments with the hydrogen-flame. That flame was well known to have been strongly recommended by Pieler, and by MM. Mallard and Le Châtelier, as being by far the most suitable and delicate flame for gas-testing, and this opinion has repeatedly received independent support.

Preliminary experiments made both in this country and on the Continent have proved that the flame-caps appearing over the hydrogen-flame are larger and much more distinctly visible than those seen over any other flame. They are probably larger, because the flame possesses an extraordinarily high temperature, and they are seen more distinctly on account of the non-luminosity of the flame. In fact, the caps over this pale and practically *non-luminous flame* are more easily seen *in the presence of the flame* than the caps over other test-flames were seen *when the test-flame itself was completely shielded from the eye.* Looking at the hydrogen test-flame itself enabled the observer to trace the cap above it far more readily than when the cap had to be traced by itself over a concealed test-flame.

The distinctness and the large size of the hydrogen-flame caps evidently rendered it possible to reduce the size of the hydrogen test-flame sufficiently to allow of its introduction into an ordinary safety-lamp. It was found possible to use a hydrogen-flame 10 millimetres (0.4 inch) in height and unshielded. This flame was competent to easily indicate and measure proportions of gas varying between 0.25 and 3 per cent., and when the flame was shielded from the eye 0.1 per cent. of gas was readily seen. By decreasing the height of the flame to one-half, proportions of gas varying from 3 to 6 per cent. could also be estimated.

The flame possessed the great advantage of being quickly

and accurately adjusted to standard height, since its tip was found to be absolutely sharp and well-defined.

Further, since the supply of gas to the flame was regulated by a valve, and was not dependent on the variable rate of vaporisation of a liquid, the flame, when once adjusted, maintained a constant standard height, being in this respect altogether more satisfactory than the flames of oil, of benzoline, or of alcohol.

Experiments were then made by introducing this hydrogen-flame, which was fed from gas contained in a compressed state in a steel cylinder, into an ordinary oil safety-lamp. By placing the hydrogen jet near the oil-wick it was found quite easy to replace the oil-flame by the hydrogen-flame, or *vice versâ*, without opening the lamp. This process could be carried out rapidly and with certainty, and without risk of losing the flame. In fact, the hydrogen-flame was found to be extremely difficult of extinction except by the effect of an explosive atmosphere.

Hence it appeared possible to construct a safety-lamp, which would furnish either an illuminating oil-flame, or a standard gas-testing flame, at will. Such a lamp would evidently yield results in gas-testing much superior in delicacy and accuracy to those furnished by any previously existing lamp.

THE HYDROGEN FLAME-TEST FOR GAS.

TEST FOR METHANE (MARSH-GAS).

IT has been already stated that Pieler, as well as MM.
Mallard and Le Châtelier, strongly recommended the use
of the hydrogen-flame for gas-testing. All attempts to in-
troduce a hydrogen testing-flame into a portable safety-
lamp, however, failed, until the suggestion was made by the
author to supply the gas from a cylinder which contained
it in a compressed condition. A general outline of the
application of the hydrogen-flame to gas-testing is given
below. Fuller details will be found on page 82.

Large Hydrogen Supply Cylinder.—A stationary
safety-lamp can be supplied with a small standard hydrogen-
flame from one of the portable steel cylinders which are
used for oxy-hydrogen flames. This supply of gas will last
for nearly 160 hours when derived from a heavy but still
portable steel cylinder holding 40 cubic feet. Such a
cylinder is 35 inches long and 5.5 inches in diameter, and
weighs 38 lbs. The ordinary larger cylinder, containing 80
cubic feet, would furnish the test-flame, burning continuously,
for nearly a fortnight. Such a cylinder, however, is not
readily portable, since it is 40 inches long by 7 inches in
diameter, and weighs 65 lbs.

Portable Hydrogen Cylinder.—In order to make
the cylinder small enough to be easily carried, its capacity
must be reduced. A cylinder 10 inches long and 3 inches
in diameter, weighing 4 lbs., and containing about 4 cubic
feet of the compressed gas, was found to be suitable.

Such a cylinder can be readily covered with leather, and carried by means of a leather strap slung over the shoulder (Fig. 13). The neck of the cylinder is provided with a metal screw valve of proper construction (Fig. 23, p. 87), which is opened and closed by the rotation of a small wheel. It furnishes a small and easily adjustable hydrogen-flame within the safety-lamp.
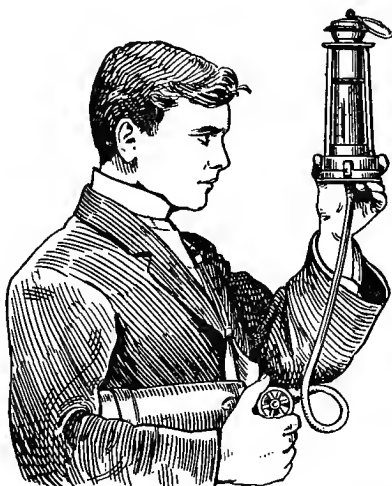
FIG. 13.—USE OF PORTABLE HYDROGEN CYLINDER WITH SAFETY-LAMP.

The standard hydrogen-flame, when fed from such a cylinder, will burn for at least sixteen hours. This renders possible nearly 2,000 separate tests for gas.

The connection of the cylinder with the lamp is made by means of a rubber tube surrounded with a wire coil. The rubber tube can be connected instantaneously by a simple arrangement either with the bottom or with the side of the lamp. The hydrogen stream, when started by opening the valve, passes through a small-bore, seamless, drawn copper tube, which traverses the oil-vessel and terminates close beside the wick-tube on a level with the wick.

By this arrangement it is easy to carry an ordinary safety-lamp for lighting purposes, and to reduce the oil-flame for detecting percentages of gas between 4 and 6. The lamp can then be connected at any moment with the hydrogen supply, and by replacing the oil-flame by the hydrogen-flame the detection and measurement of gas down to 0.25 per cent., and even down to 0.1 per cent., can be promptly effected.

It will be understood that as soon as a gentle stream of hydrogen is allowed to pass through the jet into the interior of the lamp, the hydrogen is kindled by the neighbouring oil-flame, and is seen as a tongue projecting from the oil-flame. The oil-flame is then extinguished by drawing down the wick by means of the " pricker," the hydrogen-flame is set to standard height by adjusting the valve of the hydrogen cylinder, and the cap is observed and its height measured.

In order to make the large caps visible to their extreme tip, it is necessary to lengthen the lamp-glass somewhat. A glass 3.75 inches in height has accordingly been adopted. The back of the interior of this glass is covered permanently with a dead-black film, so as to prevent reflection from the glass surface, and to throw up the pale flame and flame-cap.

The precise level to which the flame must be adjusted is given by the lowest cross-bar on a ladder-like open metal-scale which stands in front of the flame. The upper cross-bars on this scale give the heights of the caps corresponding to certain percentages of gas. The scale serves accordingly not only to adjust the flame, but also to convert the cap-height into the corresponding percentage of gas. The cross-bar is fixed 0.2 inch below the tip of the cap in every case. This enables the cross-bar to be readily seen as a black opaque line against the background of the cap. The bar would be invisible if it exactly corresponded to the tip of the cap.

The following diagram (Fig. 14) will explain the construc-

tion and use of this scale.   The scale is held in position
by the screw collar on the oil-vessel.   It can be removed
when it is not required.   As soon as the estimation is
completed, the wick is pushed up by the pricker.   It is
thus rekindled by the hydrogen-flame.   The hydrogen supply
is then shut off.

STANDARD OIL-FLAME AND CAPS. | STANDARD HYDROGEN-FLAME AND CAPS.

Percentage of Gas.   Height of Caps.   Height of Caps.   Percentage of Gas.

The tip of the cap is 0.2 inch above the Scale lines except for 6 p.c.
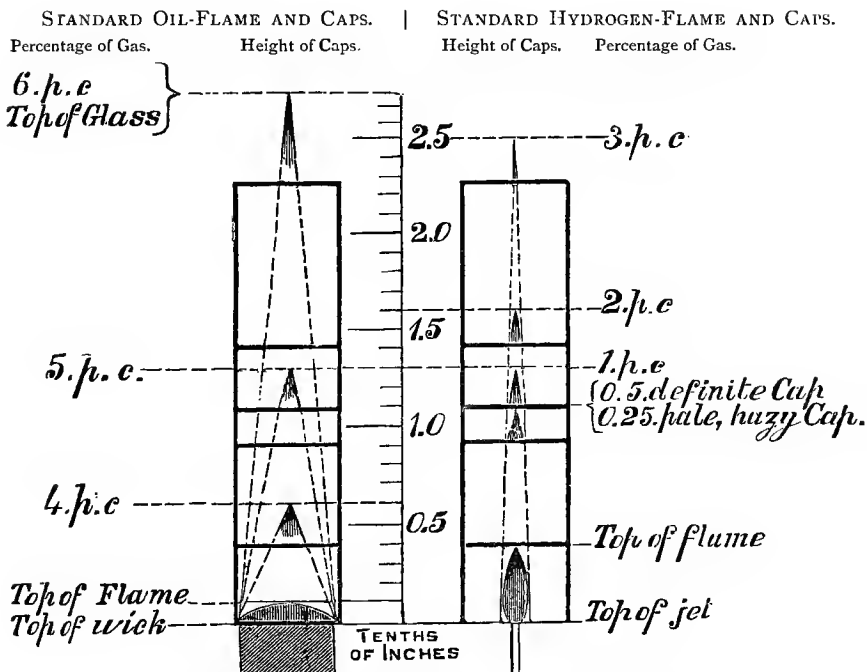
FIG. 14.—METHANE FLAME-CAPS AS SEEN AGAINST THE METAL SCALE.

The actual height of the test-flame and caps are here re-
presented diagrammatically (Fig. 14).   The coloured frontis-
piece gives a very good impression of their appearance and
colour.   The heights of the caps are recorded in the second
column of the table on page 116.

Pocket Hydrogen Cylinder.—In order to render the hydrogen supply still more portable, and to dispense with the long flexible connection with the lamp, a small light steel cylinder for the compressed hydrogen has been made. Each cylinder weighs about 14 ounces only, and several such cylinders can readily be carried in the pocket. When a cylinder is fully charged with gas, it furnishes the standard hydrogen-flame in the lamp for over two hours continuously.
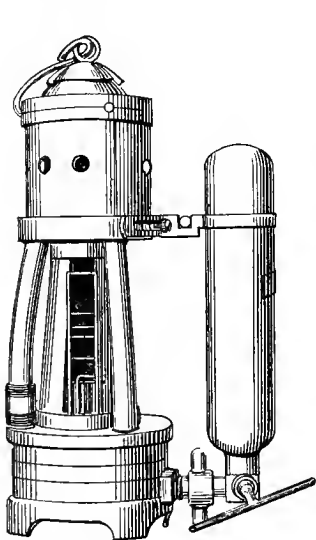
FIG. 15.—SAFETY-LAMP WITH ATTACHED HYDROGEN CYLINDER.
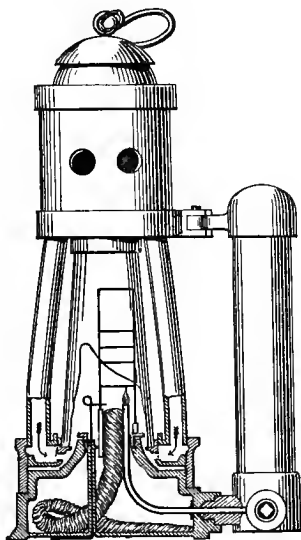
FIG. 16.—SAFETY-LAMP WITH ATTACHED HYDROGEN CYLINDER (SECTION).

The pocket cylinder is charged by being connected with a large store-cylinder. Several hundred charges may be thus introduced before the large cylinder requires to be refilled.

The small cylinder is rigidly connected with the lamp, when the hydrogen-flame is required, by attaching it at both ends to the lamp (Figs. 15, 16). This attachment can be made by two different methods (see p. 87); each method

enables the cylinder to be attached to the lamp in a couple of seconds.

The cylinder, when it is attached to the lamp, serves as a most convenient side-handle, by which the lamp may be held and supported during the adjustment of the hydrogen-flame and the examination of the flame-cap (Fig. 17). This small cylinder is adapted to an improved form of Gray's safety-lamp, which is acknowledged to be the best gas-testing lamp yet produced. The oil-flame is employed in the lamp as usual for lighting and for detecting and measuring from 4 to 6 per cent. of gas.

FIG. 17.—USE OF SAFETY-LAMP WITH POCKET HYDROGEN CYLINDER.

The hydrogen cylinder is attached to the lamp only when from 3 to 0.1 per cent. of gas is to be found and measured. The lamp with the special attachments is therefore intended for use by the officials of the mine, and not by the working miner.

If gas cannot be detected by the appearance of a cap over the reduced oil-flame, the examination is continued by means of the hydrogen-flame. When the observations are to be made by means of the hydrogen-flame, the pocket-cylinder

is attached to the lamp, in which the oil-flame is burning as usual. The cylinder is then grasped by the left hand, and the lamp is held with the flame on a level with the eye, the metal scale intervening between the eye and the flame (Fig. 17).

The key is then taken in the right hand, and is fitted upon the square head of the cylinder-valve. The valve is slowly turned round by the key until a small tongue shoots up from the oil-flame. This indicates that the hydrogen is issuing from the jet, and is kindled.

The wick is now drawn down with the right hand by means of the " pricker " until the oil-flame is extinguished, and the hydrogen-flame is at once adjusted to standard height by means of the cylinder-valve. When the tip of the hydrogen-flame has been brought precisely level with the lowest cross-bar on the scale, a careful examination for a flame-cap is made.

If no cap is seen, the gas present in the air cannot amount to 0.25 per cent. ; it cannot even attain to 0.1 per cent. if the lamp glass is fairly clean and the observing eye is in a sensitive condition. If a cap is seen, its height on the scale is noted, and the corresponding percentage is inferred from a reference to, or recollection of, the scale-card (Fig. 14, p. 57).

When the observation has been finished, the wick is pushed up by the "pricker." The oil-flame is at once re-kindled by the hydrogen-flame. The hydrogen gas is then turned off by means of the cylinder-valve. The cylinder is removed, and returned to the pocket together with the valve-key. The lamp is now an ordinary illuminating lamp again.

In experienced hands the whole procedure of making a measurement of gas by means of the hydrogen-flame can be carried out in thirty seconds. This time is reckoned from the passage from the illuminating flame to the return again to that condition.

The height of the hydrogen-flame has in all the preli-minary experiments been adjusted in the air containing the

firedamp, hence the test is made with precision and certainty by adjusting the standard flame in the atmosphere under examination, and on the spot where the test is made, and it is not necessary to adjust it first in fresh air.

The standard height of the adjusted hydrogen-flame is maintained for several minutes, after that the flame falls and the cylinder-valve must be slightly opened. If the height of the flame falls quickly, it is a sign that the store of hydrogen is nearly exhausted, and a fresh cylinder must be attached. Under no circumstances is the flame quickly lost by the falling of the flame; ample time is given for the replacement of the spent cylinder by a fresh one.

It will be noted that the proportions of gas from 3 to 6 per cent. may be measured with accuracy by reducing the hydrogen-flame to 5 millimetres (0.2 inch). But this may also be effected satisfactorily by means of the oil-flame, which has been reduced in size until its luminous tip nearly vanishes. The scale for measuring flame-caps (Fig. 14, p. 57) serves to estimate the height of the caps over the reduced oil-flame also, the top of the lamp-glass corresponding to the highest proportion of 6 per cent.

An examination of the scale-diagram (Fig. 14) shows that in all cases the tip of the flame-cap is 5 millimetres (0.2 inch) above the scale-mark. It is found impossible to observe accurately the exact contact of the tip of the cap with the scale-mark. Accordingly the scale-levels are placed 0.2 inch below the cap-height for each percentage. When the cap has its full height, it therefore surmounts the scale-mark, and shows the mark up clearly opaque black against the cap as a background.

It will be found that a little experience will render unnecessary the use of the scale when the greatest accuracy is not required.

Trials of the lamp in the ventilation current of the pit and in an air-current containing known percentages of gas, and moving at the rate of 300 feet per minute, showed that the indications were identical with those in still air.

An ordinary amount of coal-dust in the air produced no effect; but when the air was charged as fully as possible with the finest coal-dust the hydrogen-flame became luminous, and no caps could be seen.

The lamp was found to be absolutely safe in all currents of air containing gas, and with either one or both flames burning.

Fuller particulars concerning both the lamp and the hydrogen cylinder will be found on pages 86-101.

The Hydrogen-Flame as an Auxiliary to the Oil-Flame.

There are other advantages incidental to the use of the hydrogen-flame besides the very satisfactory flame-caps which it yields. This flame resists extinction by rapid movements of the lamp or of the surrounding atmosphere to a far greater extent than any other kind of test-flame does. The naked hydrogen-flame cannot be extinguished by any ordinary air-current; and when the flame is protected by burning within the safety lamp, it cannot be extinguished by swinging the lamp even in the strongest ventilation current.

The flame also possesses an extraordinary power of resistance to extinction by carbonic dioxide gas (carbonic acid). It requires for its extinction the presence in the air of an amount of carbonic acid four times as great as that which is necessary for the extinction of the oil-flame or the alcohol-flame.

Hence in localities where the flame in the safety-lamp runs the risk of being lost, either by movements of the lamp or of the external air, or of both, or by the presence of large proportions of carbonic acid, the hydrogen-flame may be burnt beside the oil-flame. If the oil-flame undergoes extinction, the wick will be rekindled by the hydrogen-flame which will remain burning, when the lamp is once more brought into favourable conditions. This method of preserving the flame in the lamp has frequently proved of the greatest value.

Detection of Carbon Dioxide by the Hydrogen-Flame.

It has been noticed that the reddish colour of the hydrogen-flame turns to pale blue in the presence of carbon dioxide. This change of colour commences when only 2 per cent. of carbon dioxide is present in the air, whereas 10 per cent. is necessary to reduce the size of the oil-flame, and 15 per cent. to extinguish it. About 10 per cent. of carbon dioxide also is dangerous when breathed in the air. Hence, while the hydrogen-flame maintains itself in the presence of a large proportion of carbon dioxide, it gives by its change of colour far more delicate indications of the presence of this gas than the oil-flame can furnish ; and it affords ample warning of a dangerous condition of the air due to carbonic acid.

Collection of Air for Testing.

In cases where the gas cannot be safely or conveniently tested for *in situ* by the portable lamp just described, a sample of the air may be collected and examined by means of a stationary hydrogen-flame, as is described hereafter (p. 172). An alternative plan is to force the air over a hydrogen-flame by means of rubber balls provided with valves (p. 181). Where only larger percentages of gas have to be tested for and not measured, in air from places inaccessible to the testing-lamp, the small Garforth collecting ball may be applied (p. 40).

Some Statements concerning the Use of the Hydrogen Lamp for Firedamp.

This Composite Hydrogen Lamp is now being used in many collieries. It has served to detect and measure gas in the " main returns " of several of our largest and best managed pits, much to the surprise of those who had hitherto failed to detect gas by the ordinary safety-lamp.

It should be remembered, however, that if the gas is really swept out of the colliery by the ventilation current, this gas should be detectable in the air-current as it leaves the pit, provided only that a sufficiently delicate testing apparatus is employed. It is manifestly advantageous that this small proportion of gas should be detected and measured, since its variations in amount serve as a useful indication of the efficiency of the ventilation in the whole colliery. If this delicate examination is extended to the "district returns," the opinion formed as to the condition of the ventilation is of a very complete and satisfactory nature.

The lamp has also served, in some cases of the greatest importance, to ascertain when any gas, even in minute proportion, was present in the air of certain mines. Its employment for this purpose has been voluntarily undertaken by eminent scientific and practical mining authorities, who have compared its indications under standard testing conditions with those furnished by other lamps, and have been satisfied with its superiority both in delicacy and in trustworthiness.

Some of the advantages possessed by this composite hydrogen oil-lamp may be thus summarised :—

1. It is at once a good lighting lamp, and a delicate and trustworthy gas-testing lamp. It requires, therefore, no second lamp to be carried with it, but only a small pocket attachment.

2. It is an ordinary safety-lamp, and is therefore not heavier or more complicated than those in common use.

3. It furnishes absolutely standard readings, by means of a flame which can always be set to size without doubt, and by caps at once seen and measured without difficulty.

4. It is entirely free from all sources of danger.

5. It furnishes an auxiliary flame when necessary, which prevents the risk of loss of flame under any conditions which occur in the coal-mine.

6. It serves as a test for carbonic acid.

The principle thus successfully introduced of combining a lighting lamp with a more delicate testing arrangement

has been adopted, with modifications, both in this country and in France. The flame used to supplement the oil-flame in these lamps has been a small alcohol-flame. Early comparative experiments in gas-testing, by means of a small alcohol-flame, led to the flame being discarded altogether in favour of the hydrogen-flame, for the following reasons :—

1. The alcohol-flame, when placed within a safety-lamp, was found to be too luminous to permit of the perception of small and faint flame-caps.

2. The caps produced over the small alcohol-flame by small percentages of gas, even when the flame was screened from the eye, were smaller and much less distinct than those seen over the unscreened hydrogen-flame.

3. The alcohol-flame, on account of its hazy top, could not be set with any certainty to a standard height ; and it underwent changes in size and character, which rendered it unfit to serve as a standard flame for use in the measurement of gas.

4. The flame also showed a cap, or halo, in pure air, which is easily confounded with slight cap indications ; while it became so luminous in the presence of larger proportions of gas as to hinder seriously the perception of the cap.

5. When an ordinary safety-lamp has been in use for half an hour, the lamp-glass becomes somewhat dimmed. Under these circumstances, no distinct and measurable cap is perceptible over the alcohol-flame when less than 1.0 per cent. of methane or pure firedamp was present in the air. Under precisely the same conditions, the hydrogen standard flame showed an unmistakable cap in the presence of 0.2 per cent. of the gas, and 0.1 per cent. when the flame was shielded. These tests were made with pure methane, as well as with pit gas containing a known percentage of methane.

Further, when the alcohol-flame is surrounded by a lamp-glass, the interference caused by the illumination within the glass becomes a serious hindrance to the perception of pale caps.

6. It may be added that considerable difficulty is often experienced in kindling the alcohol wick from the oil-flame, and that this is occasionally not effected at all, and the total loss of flame in the lamp is incurred.   The alcohol-flame is also lost in the mine with even greater ease than the oil-flame.

Royal Commission on Explosions from Coal-Dust in Mines, vol. ii., Minutes of Evidence, 1894, p. 66.

Report of Professor Harold Dixon, M.A., F.R.S., one of the Royal Commissioners.

" I have made a good many experiments in testing small percentages of firedamp in the laboratory, and also in some of the pits. . . . In these experiments I have especially used Professor Clowes' hydrogen lamp.   I have been quite sure of detecting by its means $\frac{1}{4}$ per cent. of firedamp. This quantity is not indicated by an ordinary lamp.   All my testings of the air at the Camerton Colliery after the explosion were made with Clowes' hydrogen lamp."

Camerton Colliery Explosion (p. 92).

" In examining the mine my attention was chiefly directed to testing for traces of firedamp in such places as appeared most likely to contain it, if any had issued from the strata. The instrument I used was Professor Clowes' hydrogen lamp, with which I had previously had considerable practice both in laboratory experiments and in gassy mines.   I have satisfied myself that the lamp will show the presence of $\frac{1}{4}$ per cent. of firedamp in the atmosphere."

Second Report of Commissioners, 1894 (p. 16).

" Tests made after the (Camerton) explosion by Professor Dixon with Clowes' hydrogen lamp, which detects gas in proportions as small as $\frac{1}{4}$ per cent., failed to reveal the slightest trace of it, either in the intake, the return, the working faces, or in the cavities caused by the falls of roof."

GAS-TESTING, AS AT PRESENT IN VOGUE IN THE COAL-MINE.

The account which has been presented of the development of methods of gas-testing in coal-mines shows that much more efficient methods are now available than were known even a few years ago. The manager can now have an examination for gas made by simple and trustworthy means, and the proportion of gas present can be reported to him even when it is as low as 0.1 per cent.

The remarkable diminution of damage to property, and of injury and fatality to men from explosions in the mine, which has been progressively secured since Government inspection of collieries was introduced, shows how much the security of the mine may be advanced by the regular observance of suitable and reasonable precautions. When it is remembered that in the method of gas-testing adopted in the coal-mine practically no advance has been made during that period, it will be understood that at least one cause remains which will account for the explosions which still occur.

In most of our English coal-mines it is still considered satisfactory to report "no gas present," after testing with a lamp which confessedly cannot detect with certainty 2 per cent. of gas. Such reports are made, although it is well known that only very bad ventilation could permit of 2 per cent. of gas being present in the purer part of the mine-air, and in the face of the statement, made on the best authority, that less than 1 per cent. of gas is sufficient to render air containing a suitable amount and kind of fine coal-dust violently explosive. Even when more careful gas-testing is carried out, it is not unusual to adopt a lamp which cannot under the ordinary conditions of the test detect less than 1 per cent. of gas. And relying on tests thus carried out, "no gas" is reported to be present.

The question of the presence of even minute quantities of

gas becomes extremely important when fine coal-dust is present in the mine and may be raised into the air.

The statement of the case was very fairly made in the *Colliery Guardian* for December 13, 1895, in the following terms :—

" The Royal Commissioners on coal-dust are of opinion that there is ' no probability that a dangerous explosion of coal-dust alone could ever be produced in a mine by a naked light or ordinary flame,' but that it may originate in ' a blown-out shot or other violent inflammation. To produce such a result, however, the conditions must be exceptional, and are only likely to be produced on rare occasions.' On the other hand, ' the danger of explosion in a mine in which gas exists, even in very small quantities, is greatly increased by the presence of dust. Different dusts are inflammable, and consequently dangerous, in varying degrees ; but it cannot be said with absolute certainty that any dust is entirely free from risk.'

" Such statements represent not only the opinion of the Royal Commissioners, but the opinions also of those practical authorities who have given their evidence before the Commission. They immensely strengthen the view already stated, that in neglecting suitable and satisfactory methods of gas-testing in the coal-mine, and in being content to state that the absence of a minimum quantity of 2 per cent. of gas, which is all that is now possible of detection, means ' no gas present,' our colliery managers are pursuing a policy fraught with danger, and are content to remain altogether behind the state of present knowledge in one of the most important departments for securing the safety of the mine and its numerous inmates.

" There has been much discussion during the last few years respecting the possibility of colliery explosions being originated in air containing coal-dust only, in the absence of gas. Opinion seems now to be veering in the direction of conceding this possibility. How far the conversion of those who withstood the original statement, that the presence of

gas is unnecessary, rests on satisfactory foundation, may, however, well be called into question.

" The experiments of Mr Hall were certainly of a startling nature. They undoubtedly proved that under certain conditions coal-dust, when thickly disseminated through the air, could be fired by means of a large flame and with powerfully explosive results. But there were not wanting those who stated that many of Mr Hall's conditions were such as would not be met with in the work-a-day pit. Such objectors naturally preferred to wait and watch for pure dust explosions occurring in the ordinary work of the colliery.

" Even the Camerton disaster was by many felt to furnish convincing evidence of a pure dust explosion. It is true that the pit was most carefully examined for gas after the explosion. The examining party included a Royal Commissioner, armed with the most delicate and accurate portable gas-testing apparatus yet invented. With this apparatus the Commissioner stated that he was quite sure of detecting $\frac{1}{4}$ per cent. of gas. He might have safely fixed the limit even lower than this. Evidently, however, the application of this trustworthy test for gas would have, to certain minds, proved more satisfactory if it had taken place at intervals *before* instead of *after* the explosion.

" There are not wanting, however, cases where pits have been professedly carefully and systematically tested for gas in their main ' returns ' with negative results. In such a pit an explosion has occurred in due course ; highly responsible officials are at once prepared to state that no gas has been detected in the pit for a long period of time, and are even occasionally known to pronounce that no gas was present in the pit. The statement that no gas is present in the pit, it will be noted, is simply another form of that which assures us that no gas has been detected. Unfortunately, however, the non-detection of gas does not necessarily correspond to its non-presence.

" The argument then proceeds thus : No gas being present in that part of the unfortunate pit which has suffered

from the explosion, it is evident that the usual explosive agent was not the cause of the disaster. Another cause must be found, and coal-dust, which is usually present, is fallen back upon as a ready explanation of the occurrence. Here, it is said, is a satisfactory proof, which appeals to the most practical man, that coal-dust in the absence of gas is a dangerously explosive substance.

" There is a flaw, however, in this process of reasoning which only requires to be pointed out in order to be appreciated. It has been stated by Mr Galloway that the presence in the air of an amount of gas not exceeding 1 per cent. is competent to render coal-dust in air easily explosive. All investigation of this question has tended to support Mr Galloway's statement, and, as a matter of fact, it is now generally accepted.

" Evidently, if so small an amount of gas gives rise to danger in the presence of coal-dust, the question whether dust explosions can occur in the absence of gas resolves itself largely into careful and delicate gas-testing.

" Now, although the law requires gas to be tested for, and to be reported when found, there is no requirement made as to the use of testing apparatus which shall ensure that 1 per cent. of gas—the dangerous limit—is not reached. Each official, whose duty it is to test for gas in the pit, practically settles for himself and with his own conscience how thorough and exhaustive his examination for gas shall be. And, unfortunately, there are only too many instances of officials testing for gas with apparatus which certainly at the very best can only doubtfully and with difficulty detect 2 per cent. ; while many even of the more scrupulous should know that the means of testing which they employ would assuredly find nothing less than 1 per cent.

" In the face of Mr Galloway's statement already referred to, it is not going too far to state that there is no instance on record of an explosion occurring in a working pit which has been certainly proved to be due to dust alone, unaided and uninfluenced by the presence of gas. The Camerton comes

nearest to proof absolute, but even this presents a doubtful point to the minds of some. If those whose duty it is to undertake the regular gas-testings would first loyally satisfy themselves that the testing apparatus which they employ could in its working condition, as used in the pit, detect far less than 1 per cent. of gas, our evidence as to pure dust explosions would soon rest on a more satisfactory basis.

" It is difficult to believe that the usual gas-testing procedure, above referred to, any longer rests upon ignorance. It is very generally felt that the requirement to report gas when found, without defining the amount, is a direct inducement to avoid the delicate testing upon which the safety of any pit, and more especially that of a dusty pit, depends.

" Until the law is altered, it evidently devolves on those who lead in the coal-mining industry to treat the question of gas-testing in the highest spirit. This procedure would undoubtedly conduce in the long run to economy in working the pit, because it would lead to greater safety of life and property. But such accurate and delicate gas-testing would also gradually afford a satisfactory solution of the problem as to the degree of danger arising from coal-dust *per se*."

DETECTION AND MEASUREMENT OF
COAL-GAS IN AIR.

Coal-gas is usually detected in the air by its peculiar smell. The detection of the presence of coal-gas in air by some test more trustworthy than that of the sense of smell is, however, frequently a necessity.

Not only is the sensitiveness of an individual to the perception of odours very variable, and sometimes absolutely non-existent, but authenticated instances exist of coal-gas having been entirely deprived of its odorous constituents.

Occasions arise, therefore, in which reliance upon the sense of smell may lead to the assumption that coal-gas is absent when it may actually be present in dangerous amount.

It must be remembered that the combustible gaseous constituents of coal-gas are practically free from any pronounced odour, and that the substances which are usually smelt in the gas are condensible vapours. These vapours may be removed from the gaseous mixture by absorbent substances; and it has been shown that certain kinds of soil exert such an absorbent effect. Hence coal-gas which has traversed porous soil may mingle with the air, and be unperceived even by individuals in whom the sense of smell is normal.

Further, it is very difficult, if not impossible, to form any notion of the proportion of coal-gas which is present in the air from the intensity of its smell. It is necessary to use a suitable gas-testing apparatus in order to ascertain this proportion.

The detection of coal-gas and the measurement of the amount which is present in the air is of importance, in order that it may be known whether the proportion falls within the explosive limits (p. 2). But the detection is also necessary because coal-gas contains dangerously poisonous carbonic oxide, and this, if constantly breathed, may produce serious if not fatal results.

The reduced oil-flame of the safety-lamp may, under suitable conditions, be relied upon for detecting and measuring coal-gas with tolerable accuracy, when it is present in the air in any proportion between 3 and 6 per cent. The lamp should be of the modern improved Gray type, and should be provided with the lengthened glass, with interior dead-black coating behind, as has been already specified.

If the detection and measurement of the gas is to be extended below 3 per cent., the lamp must be provided with the means of obtaining within it, when necessary, a standard hydrogen-flame in the way already described. The hydrogen will be supplied from a pocket-cylinder or from a cylinder of larger dimensions, according as it is desired to

make the testing apparatus easily portable and movable or stationary. The use of this safety-lamp with alternative flames is described on page 58.

The caps seen over the testing-flames are similar to those in the frontispiece : their heights are stated in the following table :—

FLAME-CAPS PRODUCED BY AIR CONTAINING COAL-GAS

Percentage of Coal-Gas in Air.	Corresponding Height of Cap in Inches.		
	With Large Hydrogen Flame (0.4 inch).	With Small Hydrogen-Flame (0 2 inch)	With Reduced Oil-Flame.
0.25	0.63	...	...
0.50	0.75	...	...
1.00	1.00	...	...
2.00	1.62	...	...
3.00	2.40	0.46	0.61
4.00	...	1.20	0.80
5.00	...	2.40	1.38

It will be seen that the higher proportions of gas may either be roughly estimated by means of the reduced oil-flame, or may be measured with greater accuracy by means of a hydrogen-flame which is reduced in height to 0.2 inch— that is, to half the standard height. The lower percentages are measured by means of the standard hydrogen-flame, 0.4 inch in height.

On comparing these indications with those furnished by methane, it will be found that the cap-heights with the hydrogen-flame are somewhat higher for corresponding percentages of coal-gas than those produced by methane, while the oil-flame caps are somewhat shorter.

An indicator scale-card is shown on the next page (Fig. 18). The cap-heights are represented in tenths of inches above the zero mark, which corresponds with the top of the test-flame. The first vertical column of percentages to the left correspond to the cap-heights obtained over the small hydrogen-flame, 0.2 inch in height. The next per-

centages are those indicated by the cap-heights over the
0.4-inch hydrogen-flame. The percentages marked by

STANDARD HYDROGEN FLAMES AND CAPS, WITH
PERCENTAGES OF COAL-GAS INDICATED.
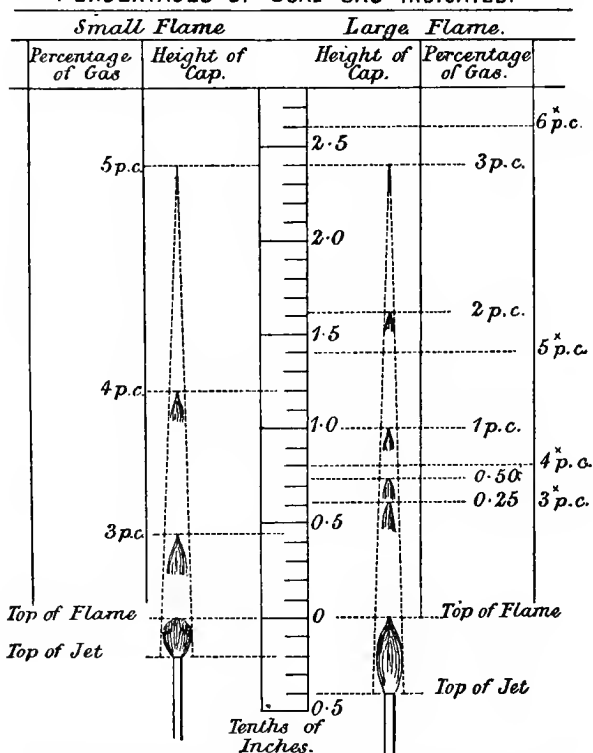
*Percentages of Coal-Gas indicated by flame-cap
heights over the reduced oil-flame*

FIG. 18.—COAL-GAS FLAME-CAPS SEEN AGAINST MEASURING SCALE.

asterisks are those indicated by the corresponding cap-
heights over the reduced oil-flame.

The detection and measurement of coal-gas in air below
its minimum explosive proportion can be made *in situ* by

means of this safety-lamp with fittings for the supply of a hydrogen-flame. It is sometimes, however, impossible or unadvisable to make the test *in situ*, and the collection of a sample of the air, to be subsequently tested elsewhere, is necessary or preferable. In such cases the apparatus described on page 172 may be employed with advantage. By this arrangement a sample of the air to be tested is collected in a suitable apparatus, and is tested by allowing it to escape over a stationary hydrogen-flame.

An alternative method consists in forcing the air over a hydrogen-flame by means of rubber balls provided with valves (p. 181). Larger amounts of coal-gas which have to be tested for but not measured, in air inaccessible to the test-lamp, may be looked for by the Garforth apparatus (p. 40).

DETECTION AND MEASUREMENT OF WATER-GAS IN AIR.

The production and use of water-gas as a gaseous fuel and for the enrichment of coal-gas has been occasionally attended with disastrous results to those engaged in its manufacture and manipulation. This gaseous mixture, containing large proportions of hydrogen and of carbon monoxide (carbonic oxide), can yield dangerous explosive mixtures with air (p. 2). But the danger has usually arisen not so much from this source, as from breathing the unburnt gas after it has been mixed with the air. The risk is due to the highly poisonous nature of the carbonic oxide, which is one of the main constituents of water-gas.

Water-gas, unless it is artificially " odorated," is practically free from smell, hence its presence in the air cannot be detected by any attendant odour. Accordingly recourse must be had to the flame-test for the discovery and measurement of water-gas in the air in the same way as this test is

applied in the coal-mine for dealing with small proportions
of marsh-gas.

Water-gas of average composition was prepared by mixing
together its constituents in the following proportions :—
Hydrogen, 49.6 ; carbon monoxide, 40.8 ; carbon dioxide,
2.6 ; nitrogen, 7.0.   In this mixture the caps were similar
to those in the frontispiece : their heights were as follows :—

CAP-HEIGHTS IN AIR CONTAINING WATER-GAS.

Percentage of Water-Gas in the Air.	Corresponding Height of Flame-Cap in Inches.	
	Over Standard Hydrogen-Flame (=0.4 inch).	Over Reduced Oil-Flame.
0.25	0.4	*Nil.*
0.5	0.58	. .
1.0	0.69	...
2.0	1.14	0.32
3.0	1.26	0.32
4.0	1.44*	0.36
5.0	1.60*	0.58
6.0	2.02*	0.80

The caps marked with an asterisk were surmounted by a
slender pale thread, the height of which was not measured
in the cap.

It will be seen that by using the hydrogen-flame 0.25 per
cent. of water-gas in the air is indicated by a distinctly
visible cap.   This corresponds to the presence of not more
than 0.1 per cent. of carbonic oxide.   This proportion of
carbon monoxide is distinctly below the minimum, which is
dangerous when breathed for a short time.   Dr Haldane *
has breathed air containing 0.2 of carbon monoxide for
more than an hour before serious symptoms were produced.

It may therefore be safely asserted that if the standard
hydrogen-flame, applied in the safety-lamp by the method

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* *Journal of Physiology*, vol. xviii., No. 3 ; and *Trans. Federated
Institution of Mining Engineers*, viii. 549, 562.

already described (p. 58), indicates no trace of flame-cap, carbon monoxide derived from water-gas cannot be present in the air in dangerous proportion.   Even if the minimum indication of o.1 per cent. is shown, the breathing of the air is not by any means attended with immediate danger.   Since, however, the carbonic oxide absorbed from the air accumulates in the blood, it must be treated as all cumulative poisons should be, and the breathing of air containing this small percentage should not be persisted in.   In cases of emergency, however, such air may be breathed for at least several hours without proving fatal.

There appears to be no means of distinguishing the carbonic oxide cap by its appearance from the cap produced by other inflammable gases already referred to.   Dr Haldane, however, mentions that a mouse is affected by breathing air containing carbonic oxide long before a man suffers from the same cause.   In a special case a mouse became powerless in two minutes in an atmosphere containing an amount of carbonic oxide which was unable to produce any effect upon a man after breathing it for fifteen minutes. Hence the effect of air containing carbonic oxide is visible on a mouse in time to warn a man that he should withdraw, and to enable him to withdraw with safety.   See also page 134.

Instead of bringing the lamp into the air to be tested, the air may be passed over the flame by the arrangements described on pages 172, 181.

DETECTION AND MEASUREMENT OF ACETYLENE.

A series of tests made in mixtures of air with known percentages of acetylene proved that the caps given by acetylene corresponded in appearance with those given by methane (see frontispiece).   But a mere trace of acetylene in air, which gives no flame-cap, colours the hydrogen-

flame yellowish-green ; this tint becomes very marked when
1 per cent. or more is present.

CAP-HEIGHTS IN AIR CONTAINING ACETYLENE.

Percentage of Acetylene in Air.	Corresponding Height of Flame-Cap in Inches.	
	Over 0.4-inch Hydrogen-Flame.	Over 0.2-inch Hydrogen-Flame.
0.25	0.7	...
0.5	0.8	...
1.0	1.1	...
2.0	1.9	...
2.5	3.0	2.2
2.75	...	3.2

DETECTION AND MEASUREMENT OF INFLAM-MABLE GAS IN THE ATMOSPHERE OF "COAL-BUNKERS."

Explosions have frequently resulted from the kindling of
an explosive atmosphere in the coal-bunkers of steamers
or in coal cargoes. It will be at once seen that the hydro-
gen safety-lamp may be used for purposes of illumination in
such confined air-spaces without risk of firing any gas which
may be present. The lamp may at any time be adapted to
detecting and measuring the firedamp, which has escaped
from the coal, in the manner already described (p. 58), or
samples of the air may be forced over the testing-flame, as
is described on pages 172, 181, without the necessity of
entering the bunker at all.

DETECTION OF INFLAMMABLE GAS IN FLUE-GASES.

It is often desirable to ascertain whether fuel is under-
going complete combustion, and whether the total possible

heat is being produced from it. The examination of the flue-gases for combustible products is usually undertaken with this object in a chemical laboratory. The knowledge may be much more rapidly gained by passing the flue-gas over a hydrogen-flame, and carefully looking for a cap. The hydrogen-flame is specially suited for this purpose, owing to its power of resisting extinction by large proportions of carbonic acid. A sample of the flue-gas may be collected and tested, if necessary, by the apparatus described on page 172, or the flue-gas may be caused to pass over the hydrogen-flame by the arrangement described on page 181.

This portable apparatus (p. 181) is the most convenient for testing for flue-gases. In using this apparatus it was found necessary to remove solid particles of soot and dust from the flue-gas, since these rendered the hydrogen-flame in the testing apparatus luminous, and therefore prevented the cap from being seen. This filtration was effected by pushing layers of fine metal gauze into the metal tube which was introduced into the flue; with this tube was connected a tube 2 or 3 feet in length, stuffed with cotton wool, and this in turn was connected with the rubber tube leading to the storage vessel, c (Fig. 45, p. 173), or to the testing apparatus (Fig. 48, p. 182).

In the case of flue-gas, which contained a high percentage of carbonic acid, it was necessary to leave an air-opening in the lower part of the vessel enclosing the test-flame, in order to prevent the hydrogen-flame from being extinguished.

If the flue-gas contains little oxygen the test-flame becomes considerably enlarged. Combustible gas is detected by the appearance of a " cap " over the test-flame.

APPENDIX TO CHAPTER IV.

DETAILED INFORMATION CONCERNING THE HYDROGEN
SAFETY-LAMP. (Proceedings Roy. Soc., vol. lxii.,
p. 482; and Cantor Lectures, 1894, Jour. Soc. of
Arts.)

BY FRANK CLOWES, D.Sc.

THE presence of firedamp is still almost invariably detected,
and its amount is more or less accurately measured, by the
observation of the pale " cap" produced by the " gas " over the
flame of the safety-lamp. When the flame of an ordinary oil
safety-lamp is suitably reduced in size by drawing down the
wick, it is generally considered that proportions of gas in the
air, varying from about 2.5 to 6 per cent., can be detected and
estimated by its means. The upper limit of 6 per cent. consti-
tutes an inflammable and, under certain conditions, an explosive
mixture (p. 2). The lower limit reached by this method of test-
ing is, however, not considered sufficiently low for the following
reasons.

1. W. Galloway has shown (*Roy. Soc. Proc.*, vol. xxiv., p. 361)
that air containing less than 1 per cent. of gas becomes explosive
when it is mingled with fine coal-dust ; hence the ordinary
safety-lamp test for gas is incapable of indicating a dangerous
state of the atmosphere in dusty mines.

2. And, further, even in the absence of coal-dust in the air of
the mine, it is necessary to test the "returns," or the ventilating
currents as they leave the working " districts " of the mine, in
order to ascertain whether the general ventilation of the mine
is well distributed and sufficient. It is stated by high authorities
that the air in the " main return " should not contain more than
0.5 per cent. of " gas," and that 1 per cent. should never be
reached. An ordinary oil safety-lamp gives no indications with
1 per cent. or less of gas, and when the air is examined by its
means, no percentage of gas less than 2 will be detected.

During the last twelve years several forms of gas-testing
apparatus have been introduced, with the object of enabling
percentages of gas as low as 0.5, and even as 0.25, to be deter-
mined. The lower proportion, 0.25 per cent., is considered to
be low enough for all practical purposes.

Of these apparatus, the following are considered to effect their purpose satisfactorily :—E. H. Liveing's electrical indicator (*Physical Soc. Proc.*, June 1880) ; Fr. Pieler's alcohol-lamp, described in a pamphlet (*Ueber einfachen Methoden zur Untersuchung der Grubenwetter*, Aachen, 1883) ; and an apparatus brought forward by Coquillion and by others, which depends upon measuring the reduction of pressure produced in a confined volume of the mine-air when the firedamp is burnt out of it, this being effected by maintaining the air in contact with a metallic wire rendered incandescent by an electric current.

Apart from general considerations of convenience and of safety when these apparatus are in use in the coal-mine, a serious objection to each of them is that it is by no means small or light, and that it must be carried together with an ordinary safety-lamp, since it does not itself serve for illuminating the darkness of the mine.

The Liveing apparatus has recently been proved by James Grundy, working with my test-chamber, to give very accurate readings of "gas," varying in percentage from 0.11 to 2.2 ; but he found the platinum wire exposed to the gas to be subject to changes when in use, which make the apparatus difficult to maintain in working order, and which sometimes render it useless.

There seems to be a general disposition amongst all classes interested in mining to improve, if possible, the flame-cap test, rather than to resort to other methods for securing accuracy and delicacy in gas-testing.   This object was in some measure attained by MM. Mallard and Le Châtelier in 1881 (*Annales des Mines*, 7th ser., vol. xix., p. 186), by suitably screening the reduced oil-flame of the safety-lamp, and then viewing its tip against a black background of cloth or of blackened metal sheet. It is stated that a slight indication was obtained by this means when the percentage of gas present was as low as 0.5.   The lamp, however, suffered a loss of illuminating power when its flame was turned up, owing to the obstruction due to the screens. The indications of the lower percentages were also confessedly extremely slight and feeble.   Still the improved lamp has the advantage of being at once an illuminator and also a gas-tester of greater delicacy than the lamps in ordinary use.

The inventors of this improved oil-lamp state that they consider the hydrogen-flame to be superior to any other for gas-testing.   They ascertained that this flame would detect 0.25 per

cent. of gas; but they do not publish any further account of its indications, apparently because their attempt to introduce the hydrogen-flame into a safety-lamp was altogether unsuccessful.

Pieler was also much impressed with the advantages obtained by the use of a hydrogen-flame for gas-testing. But as he failed in his attempts to apply this flame to a portable lamp, he recommended (*loc. cit.*) the application of the hydrogen-flame, fed by a chemical generator in a stationary apparatus above ground, to testing samples of mine-air which were conveyed to it. He confesses that his alcohol-lamp is only a substitute for the impossible hydrogen-lamp, which he would evidently recommend if it were available.

The alterations recently made by M. Chesneau (*Annales des Mines*, August 1892, p. 203) in the Pieler lamp would therefore probably not have been recommended by the original inventor of the alcohol-lamp, if a portable hydrogen-lamp had been in existence ; and although they add to the safety of the lamp, they do so by rendering the lamp heavy, and so complicated as to be troublesome to clean.

The Pieler lamp further labours under the serious disadvantage that the pale caps have to be observed through wire gauze, which obstructs much of their light. The caps become actually invisible if the gauze around the lamp is bright and reflective, as it frequently is in a new lamp.

When samples of air can be conveniently collected and carried to a testing station, no arrangement will be found more convenient and delicate than a hydrogen-flame of standard size, fed by a large cylinder of the compressed gas. The flame-cap is then observed in a dark room against a dead-black ground, and its height is noted. Such an arrangement may even be placed, with proper safeguards, in the main return of the coal-mine. A portable hydrogen safety-flame will, however, be found to be much more convenient, as it can be carried to the spot where the test is to be made. The troublesome collection and transport of bulky air samples are thus avoided, and the testing at the same time is not limited to one spot only.

A Portable Safety-Lamp, with Interchangeable Oil and Hydrogen Flames.

An arrangement for introducing a standard hydrogen-flame into any ordinary form of safety-lamp, by the use of a small

portable cylinder, was successfully tried. Arrangement was made for lighting the hydrogen without opening the lamp. The requisite supply of hydrogen was contained in a compressed state in a steel cylinder, similar to those in common use for oxygen and other gases, but of much smaller dimensions. The cylinder was slung from the shoulder by a strap, and was connected, when necessary, with the lamp by means of a length of flexible tubing. On slightly opening the valve of the cylinder, the hydrogen was fed through a copper tube of very fine bore, within the lamp, to a jet terminating beside and just above the wick of the lamp. This copper tube passed through the oil reservoir of the lamp (Fig. 19). Its diameter was far too small to permit of its passing flame.
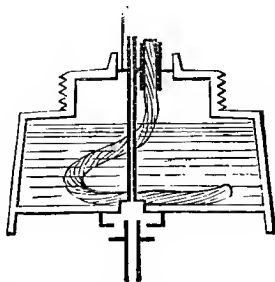
FIG. 19.—HYDROGEN TUBE IN OIL-LAMP.

The stream of hydrogen was at once kindled by the lamp-flame, and the wick was drawn down by the "pricker" until the oil-flame was extinguished. The hydrogen-flame was then set to a standard height of 10 mm. by regulating the very tapering cylinder-valve, whilst looking across a vertical 10 mm. wire fixed on the wick-holder in front of the hydrogen-flame. The flame-cap was then looked for against a dead-black background, produced by smoking with a taper a vertical strip $\frac{1}{2}$ inch wide upon the interior of the back of the lamp-glass. [This black ground is now burnt permanently upon the surface of the glass.] The lamp-glass was specially made of greater length than usual, so as to enable the whole of a flame-cap 60 mm. in height to be seen ; and the lamp selected by preference was a modified Gray-lamp, shown in section in Fig. 20. The height of any flame-cap thus observed was at first estimated by com-

paring it with the standard 10 mm. hydrogen-flame, or, if the flame had increased in height, by taking the vertical wire as the fixed 10 mm. standard of measurement.

When the observation of the flame-cap had been completed, the lamp-wick was pushed up once more against the hydrogen-flame ; and as soon as the wick had been kindled, the hydrogen
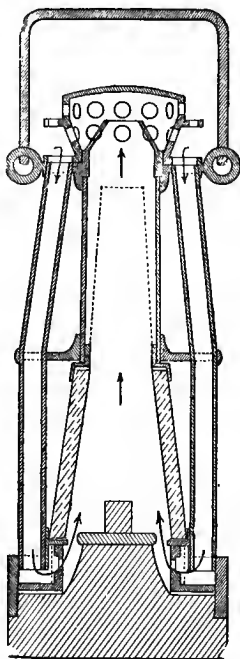
FIG. 20.—GRAY LAMP (SECTION).

was shut off by the valve of the cylinder, and the flexible tube was disconnected from the lamp.

The above process of producing the standard hydrogen-flame within the ordinary safety-lamp was very simple and was very rapidly effected ; and the change from the oil-flame to the hydrogen-flame, and the converse, presented no difficulty. A little practice enabled the operator to turn on the hydrogen

sufficiently slowly, if the valve was properly constructed ; and a little care sufficed to prevent the extinction of the hydrogen-flame by sudden shocks imparted to the flexible connecting tube.

This form of apparatus appears to be suitable for many pur-
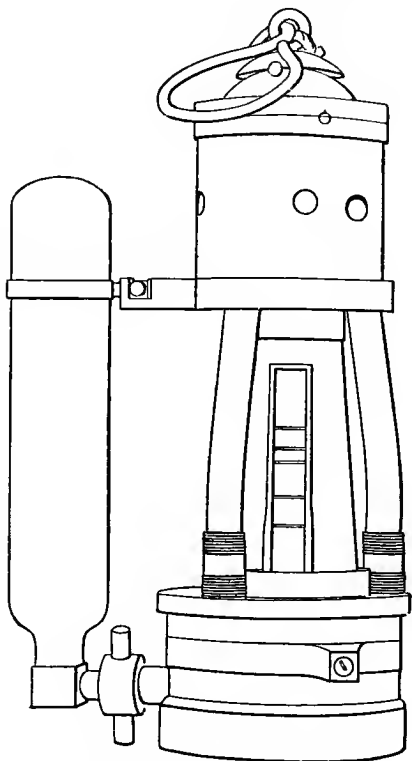
FIG. 21.—HYDROGEN CYLINDER ON SAFETY-LAMP.

poses. But practical mining men objected to the unnecessarily large weight and dimensions of the hydrogen cylinder, and to the inconvenience of the connecting tube. For making one's way along rough and awkward passages underground something more compact and light was requisite.

After many experimental forms of apparatus had been tried, a little steel cylinder directly and rigidly attachable to the safety-lamp was adopted. It is shown attached to a modified Gray safety-lamp in Fig. 21. The sectional drawing (Fig. 22) repre-
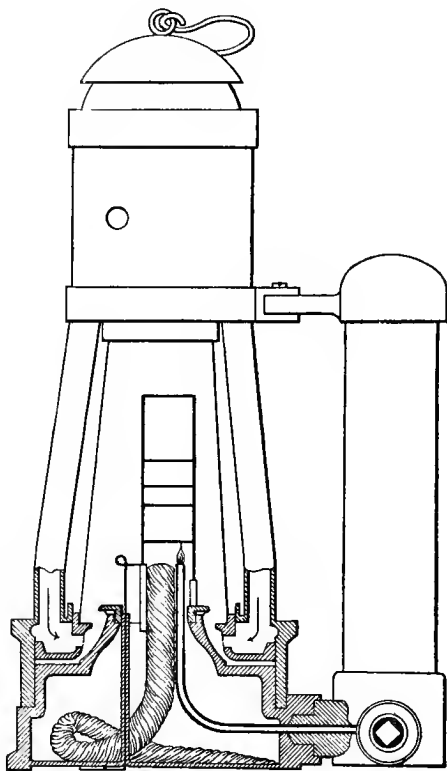
FIG. 22.—SAFETY-LAMP WITH ATTACHED HYDROGEN CYLINDER (SECTION).

sents the hydrogen tube and jet, and the scale for setting the hydrogen-flame to standard height, and for measuring the flame-caps. The small steel cylinder may be adapted to other forms of safety-lamp, but for several reasons the Gray lamp has been preferred.

The cylinder is made out of a block of mild steel; it is about 9 cubic inches in capacity, and weighs from 13 to 15 ounces with all its fittings complete, the weight varying slightly according to the method of attachment. The cylinder can be instantaneously attached to the lamp by a quarter turn on its nozzle; a clip arrangement then holds it firmly at the upper end; it is as quickly detachable. [A more recent mode of attachment (Fig. 21; and Fig. 15, p. 58) consists in dropping the upper
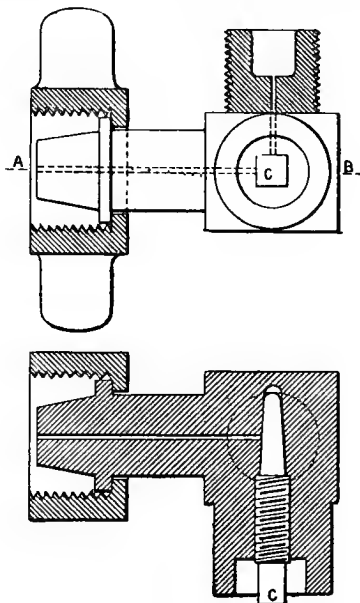
FIG. 23.—SECTION OF CYLINDER VALVE.

attachment into a claw on the lamp, and making the lower attachment by a screw coupling. This method of attachment is scarcely less rapid than the original, and possesses some advantages.]

When the cylinder is not in use, the lamp is an ordinary safety-lamp. The cylinder, when attached, forms a most convenient, strong, and rigid handle at the side of the lamp, by which the lamp may be supported in the left hand while the

hydrogen-flame is being adjusted by the right (Fig. 15, p. 58, and Fig. 17, p. 59). The whole process of passing from the bright flame to the hydrogen-flame and back again to the bright flame, including a hydrogen-flame test, is easily effected in thirty seconds.

The sections of the screw-valve of the small cylinder, shown in Fig. 23, will explain the construction of this valve. C is the screw-valve. The lower figure is a section through A to B.

The little cylinder is charged with hydrogen by connecting it with a larger store cylinder of the gas under a compression which may vary between 120 and 60 atmospheres. The charging
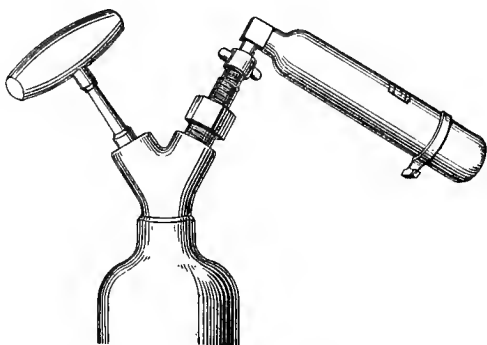
FIG. 24.—CHARGING SMALL HYDROGEN CYLINDER.

of the small cylinder is represented in Figs. 24 and 25. The original method of connecting the small cylinder with the lamp and with the large cylinder (Fig. 25) has been modified, and the form of adaptor is now simplified, as is shown in Fig. 24. The original adaptor is shown separately in Fig. 26.

When the pocket cylinder is charged at 100 atmospheres' pressure, the small cylinder furnishes the standard 10 mm. flame, burning continuously, for two hours. This would be far more than sufficient for one inspection of a mine, since the hydrogen-flame would only be used occasionally, and then for short intervals. If a longer service is required, one or more reserve cylinders can be easily carried in the pocket. The small

cylinder may be charged several hundred times, sufficiently for use, from a large cylinder under 120 atmospheres' pressure.

When "gas" is being tested for in the mine by this composite lamp, the examination would first be made in the usual way by carefully and gradually drawing down the wick, watching continuously meanwhile through the well-cleaned glass, against the dead-black background already described, whether at any stage a cap appears over the flame. If a distinct cap within the limits
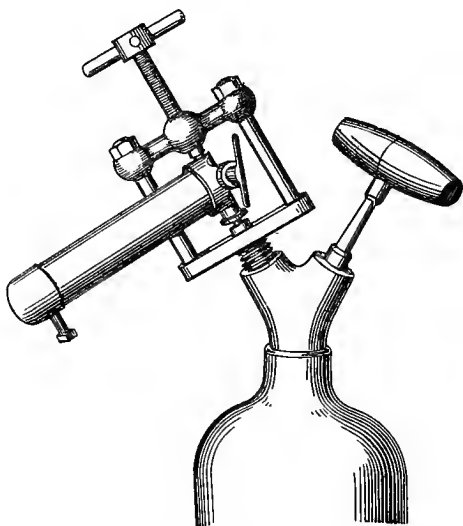
FIG. 25.—CHARGING SMALL HYDROGEN CYLINDER.

of the glass should be seen, the percentage of gas will be between 3 and 6. By noting the height of the cap against the standard scale, the percentage of gas can be ascertained with accuracy. This test may be confirmed by the hydrogen-flame, reduced to 0.2 inch in height.

If no satisfactory cap can be seen over the reduced oil-flame, and small percentages of gas have to be looked for, the hydrogen cylinder is attached to the lamp, the standard hydrogen-flame is produced within the lamp, and a cap is looked for over the flame. This standard flame will readily indicate and measure

percentages varying from 0.25 to 3, the caps being easily seen
and readily measured by the scale. The cap corresponding to
0.25 of gas is pale, and is somewhat hazy and ill-defined at
its edge ; the cap with 0.5 per cent. is much more dense and
well-defined ; but both these caps are easily seen even by an
inexperienced eye. The caps seen over the flames in this lamp
are represented, as seen against the scale, in Fig. 14 (p. 57).
This scale is now supplied as a metal ladder, which stands in
front of the flame and caps.
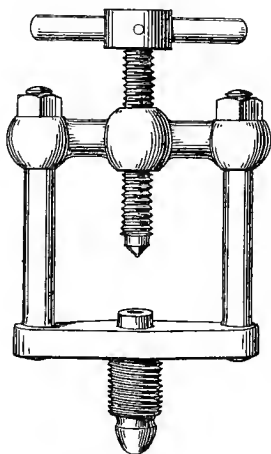
FIG. 26.—ADAPTOR FOR CHARGING SMALL CYLINDER.

The dimensions of the caps given by less than 1 per cent. of
gas can be much increased by turning up the hydrogen-flame
to 15 mm. (see $H_1 H_1$, Figs. 35, 37, pp. 117, 119). Similarly, the
cap indications of the standard hydrogen-flame, which exceed
the height of the lamp-glass when more than 3 per cent. of gas
is present, can be brought within the visible limits by reducing
the flame, while in the presence of the gas, to 5 mm. (see $H_2 H_2$,
Figs. 35, 37). These higher percentages of gas may in this way
be estimated by means of the hydrogen-flame, instead of by the
reduced oil-flame, as has been already stated.

It has been occasionally noticed that, when the hydrogen-

flame is allowed to burn for a long time within the lamp, the lower part of the lamp-glass becomes dimmed. This is due to the cooling action of the ventilation current and the feeble radiative power of the flame. Drops of water condense upon the inside of the glass, and interfere with the accurate observation of the flame and of the cap. If this should occur, it is only necessary to turn on the oil-flame for a short time ; and this, by its superior lateral radiation, rapidly dissipates the water. This deposition of moisture may be prevented by shielding the lamp-glass from the ventilating current. It is also altogether prevented by cementing a sheet of talc to the interior of the front of the lamp-glass.

It will be readily understood that the main advantages resulting from the use of the hydrogen-flame as compared with all other testing-flames are the following :—

1. The flame is non-luminous, however large it may be, and requires no shielding from the eye ; in fact, the observation of the flame assists in tracing and seeing the cap. This cannot be said of any other testing-flame, even the flame of alcohol being sufficiently luminous to interfere considerably with the perception of a faint cap.

2. Since the flame is fed with gas from a supply, it can be at once set with certainty and precision to standard dimensions, and is easily maintained in this condition. No wick-fed flame can be thus adjusted with certainty, and then maintained in adjustment.

3. The tip of the hydrogen-flame is perfectly sharp and free from all haze or halo. Even when the flame is of large dimensions, only a slender thread is seen proceeding from its tip. It is therefore not only possible to bring the tip of the flame to a scale-mark with absolute certainty and precision, but there is also no difficulty in noting the first appearance of a cap. This is not true of any other testing-flame except that of unmixed colza-oil, and this flame is found to be far too variable in character to be suitable for accurate testing.

4. The hydrogen-flame gives larger and more visible caps than does any other flame of equal dimensions. Thus, in the presence of 1 per cent. of coal-gas, the 10 mm. naked alcohol and hydrogen flames and the small naked benzoline-flame gave the following cap-heights :—

Hydrogen	27	mm.
Alcohol	19	,,
Benzoline	7.2	,,

Further, since the first appearance of a cap can be noted with absolute certainty (3), the caps yielded by 0.1 or 0.2 per cent. of gas are detected with a certainty which cannot be felt when the alcohol-flame is used. The flame also does not become luminous in the presence of larger percentages of gas, as the alcohol and oil flames do. The perception of the caps is therefore not hindered as it is with the latter flames.

5. The hydrogen-flame cannot be blown out by a vigorous air-current, which at once extinguishes all other flames. Hence, when this flame is used in a safety-lamp, it is unextinguishable by rapid movements of the air or of the lamp, which are often fatal to all other flames. In fact, the conditions met with in the mine fail altogether to extinguish the hydrogen-flame.

6. The hydrogen-flame is at once extinguished by a dangerous amount of firedamp, but it requires for its extinction the presence of no less than 58 per cent. of carbonic acid or " choke-damp " in the air, whilst ordinary flames are extinguished by 15 per cent. of this gas. Accordingly, the use of the hydrogen-flame provides against the risk of the troublesome and dangerous " loss of flame " in the mine, whether by choke-damp or by rapid or sudden movement of the air or of the flame (5).

7. While the hydrogen-flame does not suffer extinction by any amount of carbonic acid which would be found in the air of the mine, it serves, by its change in colour, as a good indicator of the presence of carbonic acid.

Comparison with the Pieler Lamp.—The indications of the hydrogen lamp have been unfavourably compared with those of the Pieler lamp. It is true that the hydrogen caps are smaller than the Pieler caps ; but, on the other hand, they are far more clearly seen, and are not subject to variation in height due to variation in the size of the test-flame. The differences of height for varying percentages of gas are easily seen with the hydrogen caps, and they present the great advantage of being sufficiently small to be included in an ordinary illuminating safety-lamp, instead of requiring a specially large lamp, which is useless for lighting purposes, and becomes doubtfully safe under certain conditions

FURTHER DETAILS CONCERNING THE HYDROGEN LAMP.

There are several matters of importance and interest in connection with the construction and use of the hydrogen safety-lamp, which are stated below, and are supplementary to the more general description which has been already given.

Rate of Consumption of the Hydrogen.—The consumption of the hydrogen gas by the standard flame has been found to be on the average 7.5 cubic inches (123 c.c.) per minute. Hence a cubic foot of hydrogen will supply the flame continuously for about 3.8 hours, or 3¾ hours.

Feed from Steel Cylinders.—It follows from the above statement that the large cylinder, 3 feet 3 inches in length, and 7 inches in diameter, which contains 80 cubic feet of gas when charged under 120 atmospheres' pressure, will feed the standard flame for 304 hours.

The more portable 40 cubic feet cylinder will furnish a supply for 152 hours.

The 4 cubic feet cylinder, which may be slung on the shoulder, will feed the flame for about 15 hours.

The small pocket cylinder, which contains 1,080 cubic inches of gas at 120 atmospheres' pressure, will maintain the standard hydrogen-flame for over 2 hours.

Pocket Hydrogen Cylinder.—This cylinder is made of the best mild steel. It is 1.5 inch in diameter, and 6.5 inches long, or 7.5 inches with its fittings. Although its weight is small (14 oz.), it possesses an ample margin of strength. It can not only resist the high pressure of the gas within, but can stand when fully charged the roughest usage without risk of fracture or even of leakage.

Each cylinder is tested by internal hydraulic pressure to 3,000 lbs. per square inch, while the maximum pressure which it is subjected to when in use is 1,680 lbs. per square inch. When the hydraulic pressure within the cylinder is gradually increased beyond 3,000 lbs., the cylinder begins to bulge under 5,600 lbs. per inch, and finally bursts under a pressure of 7,000 lbs. per square inch (Fig. 27). As is seen in the figure, however, it rips up only, without flying into pieces.

The fully charged cylinder has been subjected to violent shock and rough usage without undergoing any breakage. All chance of spontaneous explosion is absent since the cylinders are charged with hydrogen only, and never contain any coal-gas or oxygen. When a cylinder is full of air, it is well to charge it once with hydrogen, and to allow this to blow out again. It is then again charged with hydrogen.

Occasionally water remains in the cylinder from the hydraulic-testing. This causes trouble by extinguishing the hydrogen-flame. The water is removed by allowing the cylinder to stand in an upright position for some time, and then partially or entirely blowing away its supply of hydrogen, while the cylinder is still vertical.

The small cylinder, when fully charged at 100 atmospheres, increases in weight by 19 grains. If the cylinder is charged at the maximum pressure of 120 atmospheres, its weight is increased by 21 grains. These data furnish a means of ascertaining from the weight of the tared cylinder to what extent it is charged, and for learning whether the cylinder retains its weight and is therefore gas-tight. A cylinder with a properly waxed valve (Precautions, p. 101) will be found to retain its charge of gas for an indefinite period.

It may be useful to state that a cubic foot of hydrogen at 60° F. weighs 37 grains, and that 1 litre is equal to 61 cubic inches.

The small cylinder supplies sufficient hydrogen for at least 280 separate tests each of thirty seconds' duration.

FIG. 27.—POCKET HYDROGEN CYLINDER BURST BY PRESSURE.

The cylinder is attachable to the lamp by two different methods.

By one the hydrogen outlet at the bottom of the cylinder has two lateral wings, which engage themselves, as the cylinder is rotated, in grooves on the lamp. The top of the cylinder at the same time attaches itself to the lamp by a spring-clip. The attachment of the cylinder to the lamp and its subsequent detachment are extremely quick and easy processes.

According to the other method, the top attachment of the cylinder is first dropped into a double claw on the lamp. This sets the cylinder in proper position for attachment below by a screw union. This method is slightly less rapid, but is stronger, and suffers less by wear.

In Fig. 15 (p. 58) it will be seen that the upper connecting piece on the lamp is carried by a slotted piece. This enables the wear between the lamp and the oil-vessel to be taken up, and keeps the connections above and below for the small cylinder in a vertical line.

The hydrogen cylinder becomes warm during use by conduction of heat from the lamp, and by being held in the hand. No undue increase of pressure is thus caused, since the cylinder does not become more heated in this way than it is heated during charging by the compression of the gas.

Weight of the Lamp with its Cylinder.—The modified Gray lamp is now made in aluminium in order to decrease its weight. The hydrogen cylinder is also supplied with aluminium fittings for a similar reason. The cylinder attachment to the lamp is either by a screw union or by a simple sliding joint. The weights of these different arrangements are as follows :—

	Lbs.	Oz.
Aluminium lamp	1	9
Oil and wick	0	2
Cylinder with aluminium fittings and screw union -	0	12
Total weight	2	7

	Lbs.	Oz.
Brass lamp	3	13
Oil and wick	0	2
Cylinder with brass fittings and screw union	0	15
Total weight	4	14

	Lbs.	Oz.
Brass lamp with simpler fitting	3	7
Oil and wick	0	2
Cylinder with simple fitting	0	14
Total weight	4	7

Lamp Gauze.—Some makers prefer to put copper gauze into their safety-lamps instead of the best steel-wire gauze. The steel gauze presents the inconvenience of rusting, and therefore of requiring more frequent renewal than the copper gauze does. But the substitution of copper for steel is to be deprecated on the ground of its greatly decreasing the safety of the lamp.

If either the oil-flame or the hydrogen-flame is allowed to play against the upper copper gauze, or if firedamp should be kindled and burn within the lamp, the copper gauze is burnt and weakened much more rapidly than the steel gauze. The continued play of the flame upon the copper gauze may even burn a hole in it, and thus render the lamp useless as a safety-lamp ; and the high temperature of the hydrogen-flame causes this flame to affect copper gauze more rapidly than the oil-flame or the flame of firedamp affects it.

The standard hydrogen testing-flame cannot possibly come into contact with the upper gauze in the Gray lamp, and a large hydrogen-flame will never be produced if proper care is used in turning the cylinder valve. The valve of the hydrogen cylinder is made to open so gradually, and is so completely under control by means of the large key which turns it, that only a careless operator could open the valve too widely, and allow a large hydrogen-flame to play against the gauze. Even if the mistake were carelessly made, it would be at once rectified.

In order to ascertain, however, if any danger could arise from this source, the hydrogen-flame was lighted at the jet within the lamp, and the valve of the hydrogen cylinder was opened as widely as was possible consistently with maintaining a flame burning. A tall flame was thus made to play upon the steel-wire gauze at the top of the lamp. In sixteen seconds the gauze became red-hot at one point on the top, but the hydrogen-flame could not penetrate the gauze, nor could a stream of marsh-gas be kindled when it was thrown upon the outer surface of the heated gauze. The hydrogen supply from four fully-charged cylinders was allowed to burn itself out against the gauze, and not only was the gauze not perforated, but it was not even softened or weakened by this treatment.

The flame, which was thus allowed to play upon the gauze, would never be produced in the lamp except by great carelessness ;

and even if the flame were produced by recklessly overturning the valve, it would be at once reduced by checking the valve. Such a flame is never produced, except purposely, by any one who has previously handled the lamp. If, however, the valve should be opened too widely, the above experiments show that it is not attended with danger to the steel gauze, or with risk of firing gas.

If any user of the lamp cares to provide against what is shown to be an imaginary danger, he could have a double gauze provided at the top of the lamp. He could also have a check-pin fitted to the valve, which prevents the possibility of opening the valve sufficiently to obtain a flame much larger than the standard 0.4-inch flame. It may be stated that this valve-check was formerly used in the lamp, but its use has been discontinued because there seemed to be a consensus of opinion that it was unnecessary.

Prevention of Reflection from the Lamp.—It has been mentioned that reflection of the light of the flame and flame-cap from the back of the lamp-glass must be prevented by coating the interior of the back of the glass with a dead-black film. Great advantage is also obtained, more especially when the reduced oil-flame is being used, by covering with a dead-black coating the upper part of the oil-vessel, the interior of the lamp pillars, and in fact all metallic surfaces which can reflect light from the flame to the eye. Such reflected light interferes seriously with the perception and measurement of pale and small flame-caps.

The interference from the above causes, however, exists to a small extent only during the use of the hydrogen-flame on account of its non-luminous character.

Makers of the Hydrogen Lamp.—The makers of the hydrogen lamp are the engineering firm of Messrs W. J. Fraser & Co., of 98 Commercial Road East, London, E. During the early and experimental stages of the mechanical development of the lamp much aid was rendered by Mr J. M. C. Paton, of the engineeering firm of Messrs Manlove & Alliott, Nottingham. The later perfection of details is largely due to Messrs Fraser.

WORKING DIRECTIONS FOR THE HYDROGEN LAMP.

Preparation of the Lamp for Use.—The lamp is charged with a mixture in equal measures of colza-oil and paraffin (water white) oil; it is trimmed in the usual way.

The mixture of the colza with petroleum is recommended in order to prevent the charring of the wick.

An upright strip, about an inch in breadth, of the inside of the lamp-glass is made dead-black, so as to form a background for observing the flame-caps. An upright graduated brass scale can be attached to the wick-holder to give standard height for the testing-flames, and to read off the heights of the " caps."

The wick is lighted, and the lamp is closed in the usual way, and is employed as an illuminating safety-lamp in air which may contain firedamp, or any other inflammable gas or vapour.

Testing for " Gas" down to Three per cent.—A rough test is made for the larger percentages of gas by introducing the lamp into the air and watching the behaviour of the flame. If the flame seems likely to be extinguished by gas, the thumb is removed from the opening at the base of the air-tube to allow the air-feed to be taken from a lower level, and thus to "save the flame."

If it is wished to measure the percentage of gas present, the oil-flame is pulled down by the " pricker," until it just loses its bright tip and is one-tenth of an inch only in height, and the "cap" is looked for against the black background of the lamp-glass. Its height, as measured against the scale, gives the percentage :—

3 per cent. of gas yields a cap 0.3 inch in height.	0.3 inch.
4 ,, ,, ,, 0.5 ,, ,,	1.0 ,,
5 ,, ,, ,, 1.1 ,, ,,	1.6 ,,
6 ,, ,, ,, which just reaches the top of the lamp-glass.	Enters top of lamp. (See *Note.*)

Note.—Another method of procedure is to draw down the wick gradually, watching carefully for the appearance of a cap. If a cap is seen, the flame is adjusted so as to give the maximum height of cap. The percentage of gas is then found from the second column of the above table.

Testing for less than Three per cent. of Gas.—If no distinct cap is seen over the reduced oil-flame, this does not necessarily

prove the absence of "gas," since the oil-flame does not give any distinct indication when less than 2.5 per cent. of gas is present.

The hydrogen-flame, however, detects and measures gas down to 0.2 per cent. This flame is produced as follows :—

The pocket hydrogen cylinder is attached to the lamp and serves as a convenient handle. Grasping the cylinder in the left hand, and holding the lamp with the flame on a level with the eye (Fig. 17, p. 59), the hydrogen gas is *gradually* admitted to the jet in the lamp by slowly turning the square-headed cylinder valve with the key. The key is held in the right hand, which is passed round behind the lamp to reach the valve.

As soon as the hydrogen escapes from the jet, it is kindled by the oil-flame. The flame is too pale to be seen, but it causes a bright tongue to shoot up from the oil-flame. The wick is then drawn down by the "pricker" until the oil-flame is extinguished. By carefully turning the cylinder-valve, the tip of the hydrogen-flame is made exactly level with the first line of the scale, which must be seen directly in front of the flame. No error is introduced by setting the flame in the presence of the gas.

The flame is now of standard height. Careful observation is made to see if any "cap" is visible over the flame. If any cap is seen, the percentage of gas present may be judged by the height and the appearance of the "cap." Thus :—

0.25 per cent. of gas gives a 0.7 inch cap.						{ The cap is pale and hazy in outline.
0.5	,,	,,	,,	0.7	,,	{ The cap is more definite in appearance and outline.
1	,.	,,	,,	0.9	,,	{ The cap becomes not only larger, but also more visible and definite as the percentage of gas increases.
2	,,	,,	,,	1.2	,,	
3	,,	,,	,,	2.1	,,	

The Use of the Scale.—Since the flame and the "cap" are too pale to illuminate any scale placed behind them, it is necessary to place a brass scale *in front* of the flame and of the cap. It is found that the *tip* of the cap is far too pale to be seen touching the scale-mark. The cross-bars of the scale are therefore fixed 0.2 inch below the tip of the cap. Accordingly the readings for the lower percentages of gas by the hydrogen flame-cap are such as are shown in Fig. 14 (p. 57), where the thick lines represent the cross-bars of the standard scale.

Return to the Oil-Flame.—When the test with the hydrogen-flame is finished, the wick is pushed up by the "pricker," and becomes kindled by the hydrogen-flame. As soon as the oil-flame has been adjusted, the hydrogen is shut off by gradually turning the cylinder valve. The cylinder may then be detached and returned to the pocket.

The Hydrogen-Test will probably be applied principally to the "main return," and possibly to the "district returns," in order to ascertain their condition, and to regulate the ventilating-current and its distribution according to the knowledge thus obtained.

Auxiliary Flame.—In any part of the mine where the lamp may be exposed to a strong air-current, to violent or jerking movements, or to air containing a large proportion of carbonic acid, it will be found advantageous to burn the hydrogen-flame beside the oil-flame. The hydrogen-flame is not extinguished under any of these conditions ; and it therefore either maintains or rekindles the oil-flame, and thus prevents the loss of the lamp-flame.

Indications of Carbonic Acid.—If the air of the mine contains over 2 per cent. of this gas the hydrogen-flame becomes blue. Large quantities of carbonic acid are indicated by the two flames as follows :—In the presence of 10 per cent. of the gas the oil-flame begins to diminish in size, and the hydrogen-flame changes from a reddish colour to a blue-grey. In the presence of 15 per cent. of the gas the oil-flame is extinguished and the hydrogen-flame becomes more decidedly blue.

This change of colour in the hydrogen-flame progresses as the proportion of the gas increases. With 30 per cent. of carbonic acid the 0.8 inch hydrogen-flame also enlarges to 1.1 inch.

Charging of Small Cylinders.—The small cylinder is charged by connecting it by means of a special "adaptor" with the neck of a larger cylinder of compressed hydrogen (Figs. 24, 25, pp. 88, 89). The valves of both the cylinders are opened for about thirty seconds ; the valves are then closed, and the small cylinder is removed.

If a store-cylinder is not at hand, the small cylinder may be sent by parcels-post to a charging station.

A newly tested cylinder may contain water, which gives trouble by extinguishing the hydrogen-flame. The water is removed once for all by allowing the cylinder to stand in an upright position, valve downwards, and then blowing off the hydrogen.

Clearing the Hydrogen Tube of the Lamp.—It may happen that the copper tube in the lamp becomes partially stopped with oil or charred wick. It is easily cleared by blowing hydrogen through from the small cylinder.

General Precautions.—The following precautions should be observed in using the lamp :—

1. The tip of the hydrogen-jet must always be precisely 0.4 inch below the standard measure for the flame-height.

2. If the valve of the small cylinder (Fig. 23, p. 87) is found to leak, it should be unscrewed and removed by means of the key, and cleaned ; it is then rubbed with bees'-wax, and screwed again into its seat.

3. The valve of the pocket-cylinder must at first be *very gradually* opened when starting and adjusting the hydrogen-flame. A little experience will enable this operation to be performed easily and quickly.

4. It will be understood that neither the oil-flame nor the hydrogen-flame must be extinguished until the other flame is burning satisfactorily in the lamp, else the lamp-flame would be lost.

5. The hydrogen supply in the small cylinder is known to be nearly exhausted when the hydrogen-flame is observed to drop in height rapidly after it has been adjusted.

CHAPTER V.

THE TEST-CHAMBER: A SIMPLE APPARA-TUS FOR PRODUCING AND MEASURING FLAME-CAPS.

IN order that flame-caps may be produced over various flames, and subjected to examination and measurement, it is necessary that a simple means should be available for introducing the flames into suitably prepared atmospheres. While they are in these atmospheres the flames and flame-caps must further be easily visible and measurable.

The author has devised for the purpose a "test-chamber," which provides (1) for the easy and rapid production of mixtures of air with known percentages of inflammable gas or vapour, and (2) for the examination of a naked flame or safety-lamp flame in these mixtures.

THE TEST-CHAMBER.

The test-chamber is a cubical wooden box, 18.25 inches along its internal edge, and having therefore a capacity of 100 litres or 6102.7 cubic inches, without its internal fittings. The box is provided in its front with a window of plate glass (w, Fig. 28) 7 inches square; also with square apertures (A, B, Fig. 29), 6 inches square, in the bottom and in the top. This box is mounted on legs, which raise it to a height convenient for observation through the window (w), and which enable the necessary manipulation to be carried on beneath the chamber.

The chamber is carefully made, so as to be as air-tight as possible. It is then painted black inside, and is finally

rendered completely air-tight by painting it over completely, inside and out, with melted paraffin wax. The exterior coating of wax is finally melted into the wood by passing a heated flat-iron over it.

A small opening (c, Fig. 29) near the top of the chamber serves for the introduction of gas, and another (D) in the bottom of the chamber permits the replaced air to escape.
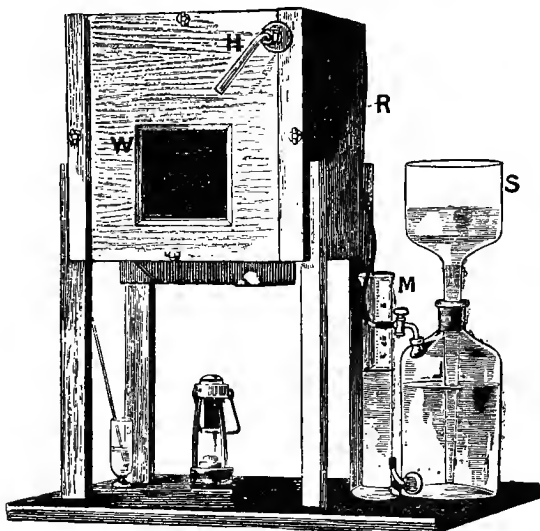
FIG. 28.—GENERAL VIEW OF TEST-CHAMBER.

The plate-glass window in front serves for observing the flame in the interior.

The flanged opening (B) below is closed by a water-seal consisting of a small zinc tray supported by buttons, and containing about 2 inches depth of water, into which the flange dips. This tray is slung from the bottom of the chamber by four rods, which keep it horizontal while it is being moved. The similar opening (A) in the top of the

chamber is surrounded with a square zinc trough containing water about 2 inches in depth, and is closed by a weighted square lid, with deep edges, sinking into the water trough (A, Fig. 29).

The lower opening (B) serves for the introduction of a safety-lamp, and several small circular openings closed by corks enable other flames to be introduced close behind the window of the chamber.
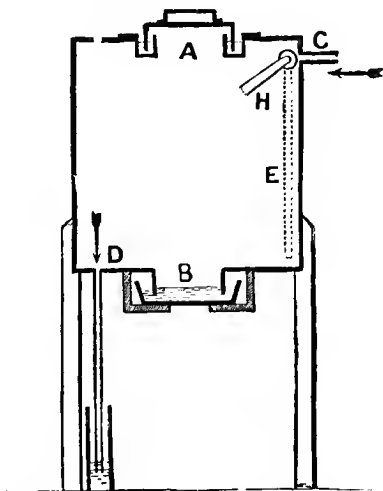
FIG. 29.—TEST-CHAMBER—SECTION FROM SIDE TO SIDE.

A mixer (E, Figs. 29, 30), which consists of a light flat black board, nearly equal in size to the section of the chamber, is suspended by an axis from the upper corner of the chamber.

The mixer is moved rapidly from the side to the top of the interior of the chamber by grasping a handle (H) projecting through the front of the chamber. By cutting away a portion of this mixing-flap (Fig. 30) the mixture in the chamber can be prepared after the lamp has been intro-

duced, and thus a lamp can be tried in a number of different percentages of gas in air without removing it from the test-chamber.

When a mixture of air with a certain definite percentage of a light gas is required, the gas is introduced into the chamber in the requisite quantity by the top inlet (c, Fig. 29). The gas displaces an equal volume of air, which
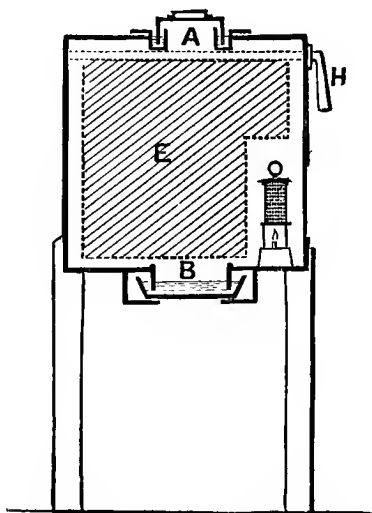
FIG. 30.—TEST-CHAMBER—SECTION FROM FRONT TO BACK.

escapes through the lower outlet (D), the exit end of which is immersed just beneath a water surface.

A vigorous use of the mixer (H) secures a uniform mixture of gas and air throughout the interior of the chamber in the course of a few seconds. The flame is then introduced into the chamber behind the glass window. The appearance and dimensions of the "cap" over the flame are noted as soon as the cap undergoes no further change.

The simplicity of arrangement of the water-seal renders the necessary opening of the chamber very brief, and the introduction and removal of a lamp many times in succession was not found to produce any appreciable effect upon the composition of the atmosphere inside the chamber. A lamp was also left burning in the chamber for a considerable length of time, and its indications underwent no change. This is due to the large capacity of the chamber and to the very limited amount of air required to support the combustion of the small flame always used in gas-testing.

The gas may be passed in the desired volume into the test-chamber from a graduated bell-jar standing in a deep vessel of water. Or a rubber balloon of the required capacity may be filled with the gas, connected with the opening (c), and then squeezed until all the gas has been transferred to the chamber.

The gas is, however, usually introduced from an ordinary glass gas-holder (s, Fig. 28). The gas outlet of the gas-holder is connected with a piece of rubber tubing (R) which is sufficiently long to reach the inlet tube (c) of the chamber. Gas is expelled from the gas-holder through this tube into the open air until all the air is displaced from the tube. The upper end of the tube is then clamped and connected with the inlet (c), care being taken that the air in the gas-holder is left at atmospheric pressure. A volume of water, equal to that of the gas to be displaced, is poured from the cylinder (M) into the empty top of the gas-holder. The water-tap of the gas-holder is then opened, and the measured volume of water is allowed to flow down and drive the gas into the chamber. As soon as the gas has been transferred to the chamber, the upper end of the rubber tube is closed by the clamp, and the taps of the gas-holder are also closed. The mixer is then vigorously worked for a few seconds, and the mixture of gas and air is ready for the introduction of the flame.

If the vapour of a volatile liquid is to be mixed with the air of the chamber, the requisite volume of the volatile

liquid is dropped through a hole in the top of the chamber upon the surface of the mixer (E). The liquid evaporates and mixes with the air of the chamber as the mixer is moved.

The chamber has stood for five minutes with the lower aperture only open, without any appreciable change occurring in the composition of the atmosphere within.

The replacement of the atmosphere in the chamber is effected by removing the water-seals from both the upper and the lower openings (A and B). The chamber, after having been used in an experiment, is then found to be filled with fresh air after simply being allowed to stand for two minutes. The process is much hastened by swinging the flap up and down several times. The complete removal of the gaseous mixture filling the chamber is thus secured with ease and certainty.

The observations are usually made in a darkened room, but the flame-caps are easily seen in a gas-lighted room, provided the direct light is not allowed to fall upon the eye or the chamber when the paler caps are being looked for. The light may be excluded by covering the head and the front of the test-chamber with a black cloth, as is done in using a photographic camera.

The presence of daylight interferes seriously with the observation of pale flame-caps. Gas-light is less objectionable, and the light of a candle or safety-lamp scarcely interferes at all. It is well to render the eye sensitive by keeping it excluded from daylight for about twenty minutes before the observation of flame-caps is commenced. A pale cap is often rendered visible if the eye is directed somewhat to one side of the flame instead of looking at it directly.

The capacity of the chamber is 100 litres, or 100,000 cubic centimetres (c.c.). Accordingly the following volumes of gas are introduced:—For 0.25 per cent. mixture, 250 c.c.; for 0.5 per cent., 500 c.c.; for 1 per cent., 1,000 c.c.; for 2 per cent., 2,000 c.c.; for 3 per cent., 3,000 c.c.; for 4 per cent., 4,000 c.c.; and for 5 per cent., 5,000

c.c.   It will be seen that a series of tests, in which the above-mentioned percentage mixtures are employed, involves an expenditure of only 16 litres of gas, a quantity far smaller than that required by any other method of testing as yet described.

Mr James Grundy has adapted the test-chamber to deliver its mixture of known proportions of air and gas into other forms of testing apparatus, which cannot themselves be in-
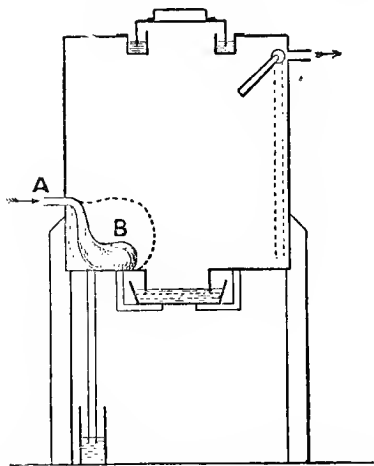
Fig. 31.—Arrangement for Supplying a Gaseous Mixture from the Test-Chamber.

troduced into the chamber.   A bladder (B, Fig. 31) was introduced into the chamber, and its neck was connected with a short pipe (A), which passed air-tight through the side of the chamber.   Before the mixture of gas and air was made in the chamber, the bladder was emptied of air by suction at the open end of the tube (A).   After the mixture had been made, the bladder was inflated by blowing down the tube from outside the chamber, and the gaseous mixture was thus expelled from the outlet tube in

the chamber, and was received into any suitable apparatus. Mr Grundy made use of this method for introducing the gaseous mixture into the Liveing's indicator.

"The test-chamber devised by Professor Clowes is the best form of apparatus existing, not only for the purpose to which it was originally put, but as a means of familiarising colliery officials and others interested in coal-mines, with the appearance of the flame-caps corresponding to different percentages of gas. It is true that they have facilities for observing the effect of gas upon the flame in the coalmine; but these observations are made with unknown percentages, and would therefore be much more successfully undertaken, and much more valuable in their indications, after repeated trials on the surface, with mixtures of known proportions of air and gas. The experience so obtained will be of the greatest value to those who will now probably have to make their examinations for gas with a more delicate and accurate flame-test than they have hitherto been accustomed to, and who will require therefore to know the exact appearance and dimensions of the caps which correspond to the different percentages of gas.

"A test-chamber for educational purposes, possibly provided with unbreakable vessels instead of with the glass gasholder and measuring-glass, might be placed in the colliery lamp-room or other suitable place. Coal-gas in place of methane might be used for mixing with air in the testchamber. The flame-caps obtained by mixtures of coal-gas and air, although not identical with those obtained by methane, only differ slightly in size and appearance from the caps obtained in mixtures of marsh-gas and air. They would serve perfectly well for training the eye of the observer.

"By means of a test-chamber placed at the colliery, young officials could thus prepare themselves for duties in the mine which necessitate a knowledge of the construction and use of delicate gas-detectors, and could familiarise themselves with the indications furnished by these detectors

in the presence of known proportions of gas." (Pamely's
" Colliery Managers' Handbook," p. 690.)

The Precise Measurement of Flame-Caps.

The test-chamber has been constantly used to accustom
those who are engaged in gas-testing to the precise appear-
ance of the caps which they will see in the presence of
known percentages of gas in the air. It was originally
employed by the author for accurately measuring these
caps.
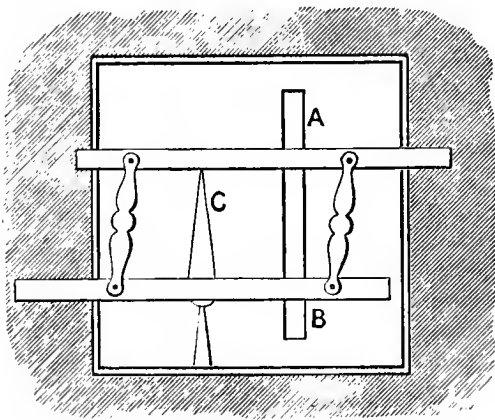
Fig. 32.—Measurement of Flame-Caps.

The measurement of the heights of flame-caps by means
of a graduated scale fixed behind the flame is impossible,
since the light emitted by the cap near its summit is far too
feeble to illuminate the scale. The method of measure-
ment described below, however, answers well.

An ordinary flat parallel-ruler is pressed against the
window of the test chamber in a horizontal position (Fig.
32), and supports a vertical strip of paper (A B) between it
and the glass. The inner edges of the rule are coated with

luminous paint, so that their position can be seen in the dark. The rule is then carefully adjusted so as to exactly include the cap (c) between its inner edges, the cap being considered to extend downwards from its apex to the tip of the flame. The position of the inner edges of the rule are then marked upon the paper strip by means of a sharply pointed pencil, and the distance thus marked is read off on a millimetre rule.

This height is manifestly less than the true height of the cap, and must be corrected by multiplying it by the distance between the eye and the cap (230 millimetres), and dividing the product by the distance between the eye and the glass (150 millimetres). See Fig. 33, in which the distances apply only to a special set of observations. See also Fig. 48, p. 182.

Flame.   *Window.*   *Eye.*

‹------- *80 m.m.* -----› ‹----------- *150 m.m.* ----------›
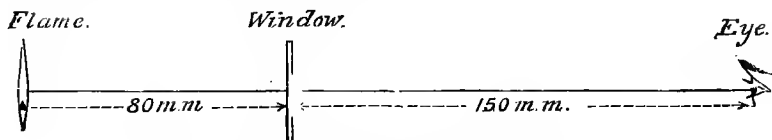
FIG. 33.—CORRECTION FOR PARALLAX.

In obtaining the results which are given hereafter, every reading was made in duplicate ; most readings were repeated many times, and in many cases were taken by more than one observer. Successive readings of the cap, produced by the standard hydrogen-flame in the same percentage of gas, were frequently identical, and rarely differed by more than 1 millimetre. In the case of flames which could not be brought with certainty to an invariable standard condition, the readings were naturally less constant, but this arose from no fault in the method of measurement adopted.

It may be noted that the only measurements which, on repetition, were closely accordant, were those of the hydrogen-flame. In the case of other test-flames, the numbers given are the average results of several more or less differing readings.

Preliminary Flame-Cap Measurements and Observations.

In the preliminary experiments with naked flames, a comparison of the " caps" produced by the reduced blue flame of the benzoline lamp, with those produced by a small alcohol-flame and a small hydrogen-flame, showed that the latter flames were more sensitive as gas-indicators than that of the benzoline lamp.   Thus naked alcohol and hydrogen flames, each 10 mm. in height, were introduced, together with the small naked blue benzoline-flame, into the test-chamber, which was filled with air containing 1 per cent. of coal-gas.   Flame-caps of the following dimensions were obtained :—

Hydrogen	27 millimetres (mm.).
Alcohol	19 ,,
Benzoline	7.2 ,,

It is true that the benzoline-flame employed in this experiment was much smaller than the two other competing flames.   But it must be remembered that the benzoline-flame is *necessarily* small when it is employed for gas-testing, since, if its dimensions are increased, it becomes luminous, and renders the pale " cap" invisible.   One of the principal advantages of the hydrogen-flame consists in its remaining non-luminous, even when it is made of large dimensions. The greater surface and higher temperature of the larger flame produces, therefore, much larger and more visible " caps" than is possible with a small benzoline-flame.   The enlarged alcohol-flame is far from being as satisfactory as the hydrogen-flame : it is much more luminous, and decidedly interferes with the perception of the caps.

It will be seen from the results of the experiment just described that the hydrogen-flame has the advantage over the alcohol-flame in the dimensions of the " cap" which it yields : it also furnishes much more easily visible caps than the alcohol-flame does.   But by prolonging the test, another advantage of the hydrogen-flame over its rival was ascer-

tained.   The two flames were allowed to burn side by side in the chamber, charged with air containing 1 per cent. of coal gas, for over thirty minutes.

Throughout this protracted test both the hydrogen-flame and the " cap " above it remained unaltered in size and in appearance.   The alcohol-flame and its " cap," however, steadily diminished in size.   After five minutes the height of the cap had fallen from 19 mm. to 12.5 mm. ; after another interval of five minutes the height of the cap was reduced to 6.5 mm. ; and thirty minutes after the beginning of the experiment the flame was spontaneously extinguished.

This result indicates that the alcohol-flame is much more sensitive to the influence of the presence of products of combustion, and to deficiency of oxygen, than the hydrogen-flame is.   The difference is due to the much smaller quantity of oxygen required by the hydrogen-flame for its combustion.   Hence the hydrogen-flame, when introduced into the ordinary safety-lamp for gas-testing purposes, may be used as an auxiliary flame to prevent the loss of flame when the lamp is carried into air containing much carbon dioxide. The hydrogen-flame remains burning and rekindles the oil-flame in purer air.

Advantage may be obtained by increasing the size of the hydrogen-flame, when small percentages of gas are being looked for.   This is shown by the results of the following experiments, made by exposing the hydrogen-flame in air containing 1 per cent. and 0.5 per cent. of coal-gas respectively ; the height of the cap being noted in each mixture when the hydrogen-flame was first 10 millimetres (mm.), and then 15 mm., in height.

	Flame 10 mm.	Flame 15 mm.
1 per cent. of gas	27 mm. cap.	50 mm. cap.
0.5 ,, ,,	23 ,,	38 ,,

Attention is directed in the above statements to the *height* of the cap alone, but, as a matter of fact, its change in general appearance is also very noticeable as the proportion of gas is increased.   Very careful observation of the

hydrogen-flame in air free from gas serves to detect a
slender and very pale thread of flame only, which cannot be
mistaken for a cap, extending beyond the top of the flame.
When the gas in the air reaches 0.25 per cent., a cap appears
which is pale grey in colour, but is still indefinite in outline,
especially at its summit, and is seen only *above* the hydrogen-
flame.

As the proportion of gas increases, the cap becomes
strikingly sharp and pointed in outline, distinctly bluish-
grey in colour, and gradually broadens and extends down
the sides of the hydrogen-flame, finally enclosing it altogether
and encircling the jet. At the same time, the hydrogen-
flame itself, when 3 per cent. of gas is exceeded, is constantly
growing in every dimension, and acquiring a rose-red tip.
It is well to have watched the above changes in the test-
chamber, and to have become familiar with the appearance
of the hydrogen-flame and cap in different percentages of
gas before the flame is used for gas-testing.

Dimensions and Particulars of Test-Flames Employed.

The lamp-flames used were of the following dimensions,
some of which are approximate only. They are drawn to
size in Fig. 34, the dimensions being shown in millimetres
and in inches :—

Dimensions of Test-Flames.

	Height in mm.*	Diameter at broadest part in mm.*
Hydrogen-flame (round)	10 15 5	5 6 4
Pieler-flame (round, conical) -	30	13
Benzoline-flame (round, conical)	3	7
Oil-flame (flat, slightly conical)	3 6	13 13

* Multiply millimetres by 0.04 to convert them into inches.

The 10-mm. hydrogen-flame (H) was adjusted to its height either in gas-free air or in air containing gas. It remains unaltered in height, in the presence of gas, until 3 per cent. of gas is reached; and this is the maximum percentage of gas which the flame is used in measuring.

The 15-mm. (H_1) and 5-mm. (H_2) hydrogen-flames were adjusted to height in the presence of the gas, since their heights are affected by the percentages of gas which they are intended to measure.

The Pieler (P), the benzoline (B), and the blue oil (O) flames were each of them adjusted in gas-free air. The
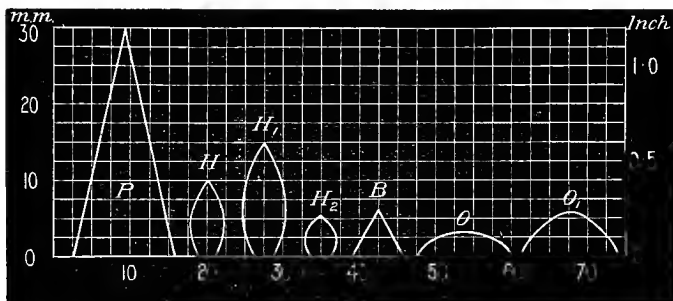
FIG. 34.—SIZE OF LAMP-FLAMES.

faintly luminous oil-flame (O_1) was adjusted in the air containing gas, the bright flame being gradually reduced until the cap was seen to be of the largest possible dimensions.

A special small aperture was required in the bottom of the chamber, beneath a safety-lamp in which an oil-flame was being burnt. This was necessary to enable the pricker to be manipulated by the thumb and first finger, in order to prevent the reduced oil-flame from sinking continuously until it became extinguished. The hole was closed by the lamp standing over it, and at other times by a small hinged lid.

MEASUREMENT OF FLAME-CAPS IN AIR CONTAINING METHANE, THE COMBUSTIBLE GAS OF "FIREDAMP."

This series of experiments was undertaken with artificially prepared methane. The results were afterwards checked by a second series in "pit-gas" of known composition.

The artificial methane was prepared by strongly heating an intimate and dry mixture of sodium acetate with caustic soda and slaked lime. The gas was washed with caustic soda solution. After it had been thus purified, it contained only 2 or 3 per cent. of free hydrogen.

The following are the corrected cap measurements expressed in millimetres, obtained in methane with the flames of the heights specified above. The caps are represented in actual size in millimetres and in inches in Figs. 36, 37, 38. In these drawings the increase in dimensions of the testing-flames, as the percentage of gas rises, is not shown. All the flames, with the exception of the Pieler alcohol-flame, were tested in the improved Gray lamp.

HEIGHTS OF FLAME-CAPS IN MILLIMETRES* OVER TEST-FLAMES IN AIR CONTAINING METHANE.

Percentage of Methane present in the Air.	Hydrogen-Flame.			Pieler Alcohol-Flame, 30 mm.	Ashworth's Benzo-line-Flame, 30 min.	Colza-Petroleum Flat Flame.	
	Standard 10 mm.	15 mm. in the Gas.	5 mm. in the Gas.			Small Blue, 3 mm.	Flame partly Luminous, 6 mm.
0.25	17	37	...	30 (?)	...	...	...
0.5	18	42	...	55	7 (?)	...	...
1.0	22	60	...	90	10 (?)	...	...
2.0	31	{ enters top of lamp }	...	{ 140 reaches top }	14	7.5	7.5
3.0	52	...	14.5	...	20	7.5	7.5
4.0	...	...	22.2	...	25	12.0	24.0
5.0	{ enters top of lamp }	...	35.0	...	30	29.0	41.0
6.0	...	...	60.0	...	35	67.0	enters top

* Multiply millimetres by 0.04 to convert them into inches.

In cases where caps of equal height are given for different percentages of gas, it must be understood that the higher percentage gives a more dense and sharply defined cap than the lower percentage does, and a little experience renders
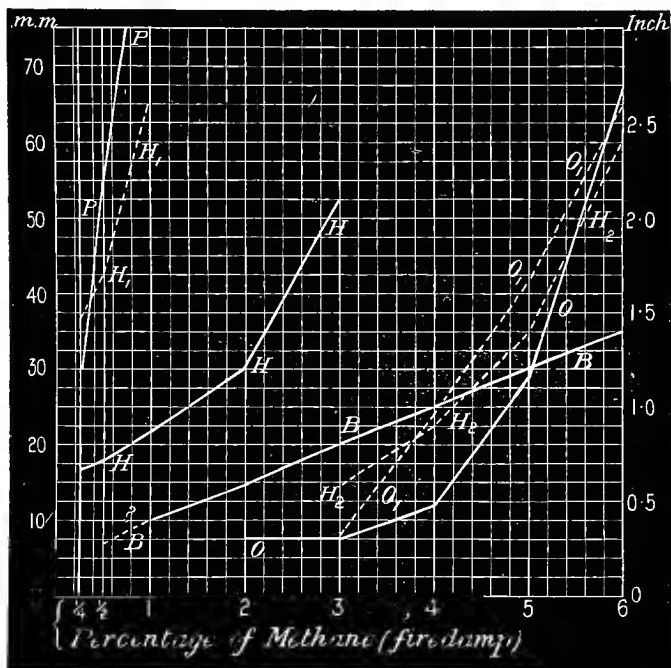
FIG. 35.—HEIGHTS OF METHANE FLAME-CAPS.

O = Colza-petroleum flat flame (blue).
O_1 =   ,,   ,,   (luminous tip).
B = Ashworth's benzoline-flame (blue).
H = Hydrogen-flame, s'andard 10 mm.
H_1 =   ,,   15 mm. in tbe gas.
H_2 =   ,,   5 mm. in the gas.

the distinction between the caps an easy matter.   A query (?) implies that the cap-measurement was not absolutely to be relied upon.

The above measurements are represented graphically in Fig. 35.

Note.—In this figure, and in Fig. 40, the height of the cap is measured upwards from the horizontal base-line oo, and the height of the cap for any percentage of gas is found by selecting the percentage on the base line, then following the vertical line upwards to the point where it is cut by the curve corresponding to the test-flame in question. The horizontal level of this point of intersection shows on the
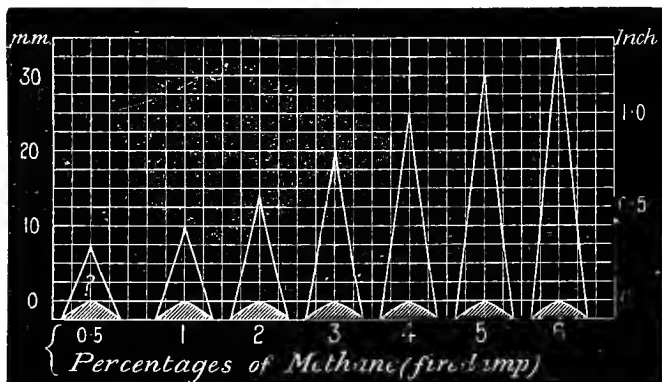
Fig. 36.—Actual Dimensions of Benzoline-Flame and Caps with Methane.

side-scales of the diagram the height of the cap. Thus (Fig. 35) for 3 per cent. of gas the vertical line from 3 on the base line is following upwards, and it is cut at 0.3 inch by o, the curve for the oil-flame; at 0.8 inch by B, the curve for the benzoline-flame; and at 2.1 inch by H, the curve for the hydrogen-flame. These are the heights of the respective caps, which are seen over these test-flames when they are exposed to air containing 3 per cent. of methane gas.

The General Conclusions drawn from these measure-

ments, and from experience obtained by working with the different lamps, are the following :—

1. The indications of the Pieler lamp begin at the lowest limit of 0.25 per cent., but quickly become too great to be
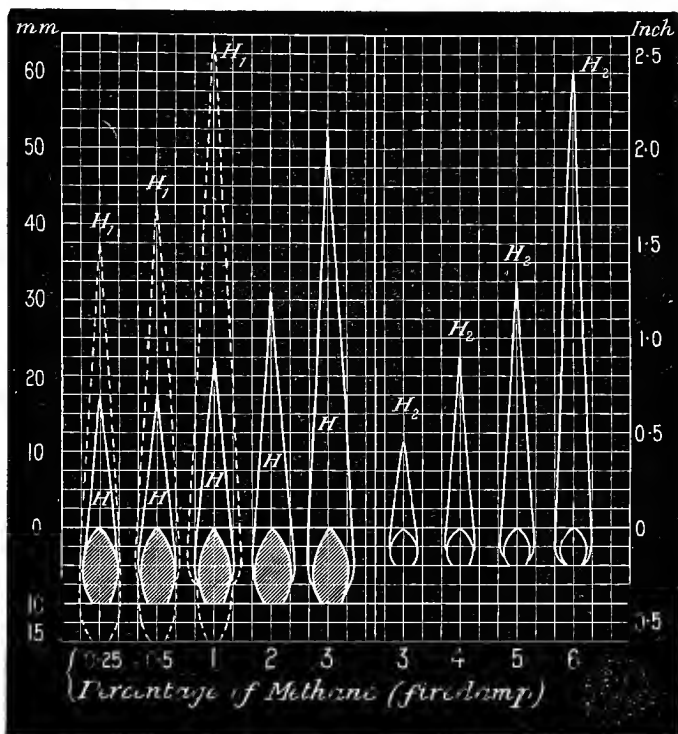
FIG. 37.—ACTUAL DIMENSIONS OF HYDROGEN-FLAMES AND CAPS WITH METHANE.
The shaded flames are of the standard 10 mm. size ; their caps are shown at H.
The dotted flames and caps (H₁) correspond to the flame set 15 mm. high in the gas.
The three figures to the right (H₂) represent 5 mm. flames and their caps ; flames set in the gas.

utilised. The hazy halo extending above the flame for several inches in pure air is, however, not distinguishable from the cap given by 0.25 per cent. of gas.

This lamp suffers under the disadvantage that much of the feeble light of the caps is lost by the obstruction of the gauze. The new gauze also frequently presents a bright reflecting surface behind the flame, and this renders the observation of the cap impossible. All the other lamps except the Davy are free from the interference due to the gauze, and if the backs of their glasses are blackened, as has been already described, they become well suited for the observation of caps.

2. The Ashworth benzoline lamp begins its indications (Fig. 36) doubtfully at 0.5 per cent., the cap thus produced being more distinct, but not greater in height, than the mantle over the flame seen in gas-free air.

But starting with an indication of 1 per cent., and a cap which is measurable when 1.5 per cent. of gas is present, it gives strikingly regular indications up to 6 per cent., and even higher percentages may be read off in a lamp with a long glass.

3. The standard 10-mm. hydrogen-flame gives distinct indications (Fig. 37) from 0.25 to 3 per cent. The cap then becomes too high for measurement in the lamp; but by reducing the flame to 5 mm., cap-readings may be taken up to 6 per cent. of gas.

The lower indications may similarly be increased by raising the flame to 15 mm.

4. The oil-flame, produced by unmixed colza-oil, gives no indications with percentages below 2 (Fig. 38). With 1 per cent. of gas, the flame from colza, mixed with an equal volume of petroleum (water-white), produces an apparent cap, which, though somewhat more intense than the natural mantle seen in gas-free air, is only equal to this mantle in dimensions, and might easily be mistaken for it.

The oil-flame, when it is reduced until it just loses its luminous tip, however, gives distinct indications from 3 to 6 per cent.

The largest indications are produced by drawing down

the flame *in the presence of the gas*, until a cap of maximum size is obtained.

A carefully regulated oil-flame may, therefore, supplement the hydrogen-flame for the indication of gas varying from 3
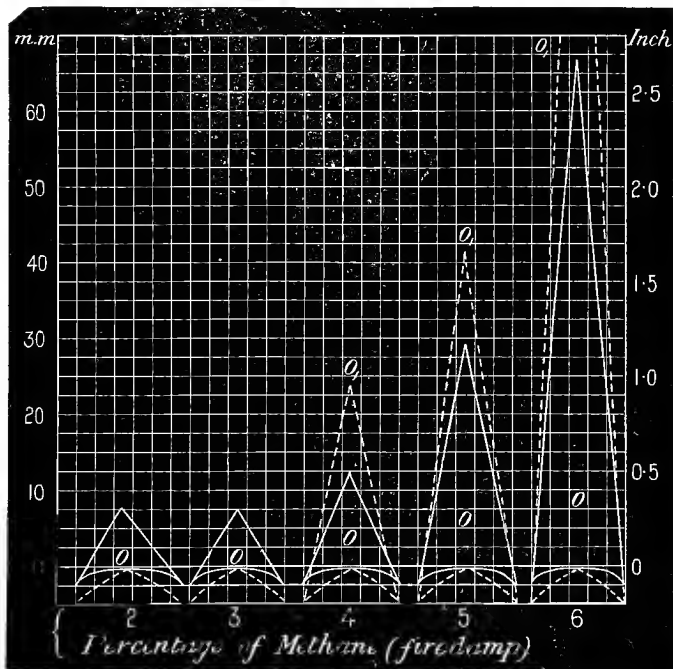
FIG. 38.—ACTUAL DIMENSIONS OF OIL-FLAMES AND CAPS WITH METHANE.

The continuous lines represent small blue flames and their caps.
The dotted lines represent caps produced when the flame was adjusted in the presence of gas, so as to give maximum caps.

to 6 per cent., and in the new hydrogen lamp this will be found to be a convenient method to adopt.

The use of colza alone in the oil-lamp is very inconvenient for gas-testing. The wick quickly chars and hardens on the

top, and the flame cannot then be reduced without danger
of extinction. The flame can never be obtained satisfactorily
in a non-luminous condition. The admixture with petroleum
obviates these difficulties.

FLAME-CAP MEASUREMENTS IN " PIT-GAS," WITH SAFETY-LAMPS IN ORDINARY WORKING CONDITION.

The careful readings of the heights of flame-caps which
had been made with chemically prepared methane were
repeated with " pit-gas." It must be borne in mind that in
the coal-mine the only gas which is estimated by means of
the flame-cap is methane. Accordingly the pit-gas should
yield flame-caps identical with those given by known per-
centages of methane, provided that the pit-gas was mixed
with the air in sufficient quantity to furnish volumes of
methane equal to those artificially prepared.

For these experiments firedamp was kindly furnished by
Dr Bedson, of the Durham College of Science, Newcastle-on-
Tyne. This gas had the following percentage composition:—

PERCENTAGE COMPOSITION OF FIREDAMP.

Methane	80.0
Oxygen	2.6
Carbon dioxide	0.8
Nitrogen	16.6

Since this gas contained only 80 per cent. of its volume of
methane, it was necessary to add 1.25 measures of it to air
in order to yield 1 measure of methane.

Mixing the " pit-gas " with the air of the test-chamber
with the above allowance, it was found that the flame-caps
obtained over the standard hydrogen-flame precisely corre-
sponded both in appearance and in height with those pro-
duced when the corresponding percentages of pure methane
had been employed.

In all the experiments made thus far in the test-chamber
the safety-lamps were used with their glasses in a freshly
cleaned condition.   But it was thought advisable to extend

the observations to lamps which had burnt for several hours, as they might have done when they were actually used for gas-testing in the coal-mine.

It had been noticed that a lamp, while it was burning, gradually deposited a whitish film on the interior of its glass, and it was thought possible that this film might interfere with the perception of pale flame-caps.

The experiments were made with the standard hydrogen-flame, with the small alcohol-flame, and with the small benzoline-flame, in separate safety-lamps.   All the lamps had been cleaned, and the oil-flames in them had then been allowed to burn continuously for two hours before they were introduced into the test-chamber.

In air containing 0.2 per cent. of methane, either artificial or as pit-gas, the hydrogen-flame showed a distinct cap; and even 0.1 per cent. of gas showed a cap if the test-flame was shielded from the eye.

The small alcohol-flame and the benzoline-flame were then tried in their lamps in the same mixture, and showed not the faintest addition to the cap always seen over the flames in gas-free air.   These two flames were then introduced in their lamps into air containing 1 per cent. of methane; no cap was seen until the flame was shielded completely from the eye.

OBSERVATION OF FLAME-CAPS IN A RAPID CURRENT OF
    AIR CONTAINING COAL-GAS, AND IN THE PRESENCE
    OF COAL-DUST.

The test-chamber was originally introduced as a convenient form of apparatus for testing the delicacy of gas-testing safety-lamps.   The chamber is far less costly and less troublesome in use, and far more economical of the gases to be tested, than the forms of apparatus previously used for the same purpose.

But it has been frequently suggested by practical mining men that the examination of the flame-caps in the still air

of the test chamber may lead to fallacious conclusions, since the " gas," when tested for in the mine, is contained in a rapidly moving air-current caused by the ventilating fan ; and this movement of the air around the safety-lamp may entirely alter the character of the flame-caps which are seen with the same percentage of gas in still air.

That any effect could be produced on the cap by the movement of air seemed extremely unlikely, since no lamp is now considered safe in the mine, the flame of which is at all affected by the ordinary ventilation current.

But while subsequently working with air containing coal-gas, which was easily obtainable in large quantity, the question was put to the test of experiment in the apparatus represented in Fig. 39.
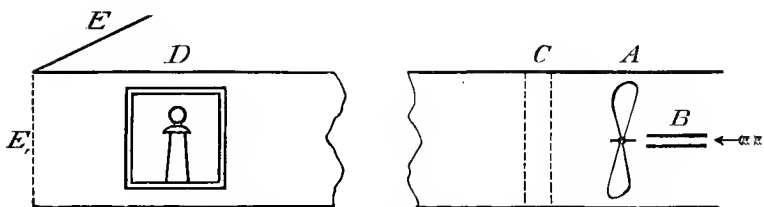
FIG. 39.—FLAME-CAP TESTS IN RAPID AIR-CURRENT CONTAINING GAS.

A square wooden tube, 12 feet in length and 14 inches square in section, had a fan (A), driven by a little electric motor, pushed into one end of it. This fan, when in rotation, drove an air-current at the rate of 300 feet per minute through the tube. A pipe (B), supplying coal-gas from the mains, fed the gas into the air-current drawn by the fan. The gas was thoroughly mixed with the air, partly by the action of the fan, and partly by the passage of the air-current through coarse wire-gauze baffles (C). The lamp was introduced through a hinged window (D).

The hydrogen-flame in the Gray lamp was not affected in the least by this air-current. The cap shown over the flame indicated the presence of 0.5 per cent. of gas. At

a given signal the hinged door (E) was dropped into position (E₁), and closed the tube, and the fan was simultaneously stopped. The lamp was thus exposed to still air of the same composition as that which was previously in motion. Not the slightest effect upon the flame or cap was perceptible.

A similar experiment made with the reduced oil-flame of the lamp, and with air containing a larger percentage of gas, showed that the air-current in motion produced no effect on the oil-flame and its cap, different from that produced by the quiescent air of the same composition.

It may be concluded, therefore, that with a good safety-lamp the test-chamber indications are applicable to the conditions ordinarily found in the mine.

It was found, however, that the presence of fine coal-dust in very large proportion in the air rendered the test-flame so luminous that no cap could be seen even when gas was present. A very dusty atmosphere will render gas-tests impossible by all the forms of testing apparatus at present known. No interference arose from the amount of dust ordinarily met with in air of the mine.

Flame-Cap Measurements in Air containing Coal-Gas.

The miner's safety-lamp is frequently employed for purposes of illumination in gas-works, and in other places in which the air may be contaminated with coal-gas. It seems, therefore, only reasonable to make the lamp also serve the purpose of detecting the percentage of coal-gas present in the air. The amount of gas thus found will indicate whether the air is in a dangerous condition. Careful measurements were accordingly made of the flame-cap heights, seen over the hydrogen-flame and the oil-flame of the safety-lamp, when the lamp was placed in the test-chamber, filled with air containing a known admixture of Nottingham coal-gas.

The average composition of Nottingham coal-gas has been already stated on page 3.

The following measurements in millimetres were obtained. They are represented graphically in millimetres and in inches in Fig. 40, but no attempt is made in these drawings to
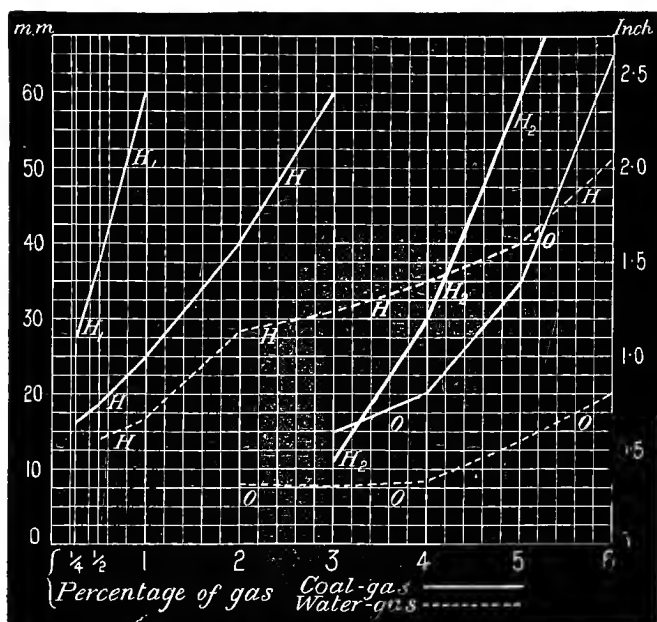
FIG. 40.—HEIGHTS OF FLAME-CAPS IN COAL-GAS AND IN WATER-GAS.

Coal-gas in continuous lines, *water-gas* in dotted lines.

HH, cap-heights over 10 mm. standard hydrogen-flame.

$H_1 H_1$, cap-heights over hydrogen-flame, reduced to 5 mm. in the presence of the gas.

$H_2 H_2$, cap-heights over 15 mm. hydrogen-flame.

OO, cap-heights over oil-flame, adjusted until the maximum cap is seen.

show the marked increase in dimensions which the test-flame undergoes in the presence of the higher percentages of gas. For an explanation of the method of using this figure, see Note on age 118.

HEIGHTS OF FLAME-CAPS IN AIR CONTAINING COAL-GAS.

Percentage of Coal-Gas in the Air.	Cap-Height in mm.* over Hydrogen-Flame.			Cap-Height in mm.* over Oil-Flame, reduced until the Cap is at Maximum.
	Standard 10 mm. Flame.	15 mm. Flame.	Flame reduced to 5 mm. in the Gas.	
0.25	15.7	27.6	...	...
0.5	18.4	37.0	...	...
1.0	25.3	60.4	...	...
2.0	40.6	...	...	...
3.0	60.0	...	11.5	15.3
4.0	...	...	30.0	20.0
5.0	...	...	60.0	34.5
6.0	...	...	enters top	65.0 (about)

* Multiply millimetres by 0.04 to convert them into inches.

On comparing these cap-heights with those given by the corresponding percentages of methane, it will be seen that they somewhat exceed the latter when the hydrogen-flame is used, and are somewhat less than the methane cap-heights when the oil-flame is employed. It is important to remember that this difference exists, if coal-gas is used to represent firedamp in the test-chamber.

RESULTS OF FLAME-CAP MEASUREMENTS IN AIR CONTAINING WATER-GAS.

The poisonous nature of " water-gas," which is produced by passing steam over red-hot coke or charcoal, is well known. It is due to the large proportion of carbon monoxide (carbonic oxide) gas present.

Since water-gas is free from odour, it is very necessary to find, if possible, some delicate method of detecting this gas, and of measuring its amount in air. Accordingly the heights of the flame-caps yielded by the hydrogen-flame, and by the oil-flame of the safety-lamp, when the lamp was introduced into air containing known percentages of water-

gas in the test-chamber, were measured. It was hoped that the flame-cap test might prove available for water-gas, as it is for firedamp and for coal-gas.

The flame-cap test, as applied to water-gas, was investigated in the test-chamber, by employing an artificially prepared mixture of the constituent gases. This mixture approximately corresponded to the average composition of water-gas. The percentages found in this artificial mixture on analysis were as follows :—

Hydrogen	49.6
Carbon monoxide	40.8
Carbon dioxide	2.6
Nitrogen	7.0

The complete series of flame-cap measurements are tabulated below, and are graphically represented in Fig. 40.

HEIGHTS OF FLAME-CAPS IN AIR CONTAINING WATER-GAS.

Percentage of Water-Gas in the Air.	Cap-Heights in mm.* over the Hydrogen-Flame.			Cap-Heights over the Colza-Petroleum Flame, Caps being of Maximum Height.
	Standard 10mm.Flame.	15mm.Flame.	5 mm. Flame.	
0.25	10	25.3	Nil	Nil
0.5	14.5	33	,,	,,
1.0	17.2	...	,,	,,
2.0	28.7	...	,,	8
3.0	31.4	...	,,	8
4.0	†36	...	,,	9
5.0	†40	...	11	14.5
6.0	†50.6	...	26	20

* Millimetres are converted into inches by being multiplied by 0.04.

† In these measurements a delicate thread of flame, surmounting the conical cap, was not included.

Since water-gas contains less than half its volume of carbonic oxide, percentages of carbonic oxide in the air less than 0.2 to 0.4, which is stated by the Prussian Firedamp Commission to be a poisonous proportion, are thus easily detectable by the hydrogen-flame test in the safety-lamp.

The Measurement of the Percentage of Gas in Air by the Spiring of the Full Luminous Flame.

It has recently been stated that the " spiring " of the full bright flame of the lamp is a very delicate and trustworthy test for gas. This effect occurs when the flame, which has been raised to the verge of smoking in air free from gas, is brought into air containing gas. The flame then stretches upwards as a thin tongue, assumes a redder tinge, loses in brightness, and begins to smoke. It is stated that 0.5 per cent. of gas may thus be detected with ease and certainty.

Experiments in the test-chamber failed to detect 0.5 per cent. of gas with an ordinary colza-petroleum flame. With a benzoline-flame, however, 0.25 per cent. was detectable ; and the spiring of the flame with 0.5 per cent. was most pronounced ; while with 1 per cent. of gas a very distinct red spiring flame was produced which smoked freely. But it was at once evident that any safety-lamp flame, when it had been delicately adjusted for this test, was very easily made to " spire " by causes other than the presence of firedamp ; this was especially the case with the benzoline-flame, which seemed to spire spontaneously at any moment.

When it is remembered that " spiring " may be caused by any slight increase in the oil supply to the wick, or by the reduction of the supply of air or oxygen to the flame, arising from any cause other than the presence of " gas," it will be seen that the indications cannot be very trustworthy.

The method is further impossible of application in many situations, since the flame must be adjusted for the test immediately before it is applied, and this adjustment must be made in air free from gas. Air known to be free from " gas " is not obtainable in many situations where the test would have to be carried out.

This test is also attended with troublesome results, since it clogs the meshes of the gauze with soot, and thus impedes the proper action of the lamp.

The conclusion, drawn from a series of comparative

experiments made in the test-chamber, was that the flame-cap test when carried out in the way already described, and with the apparatus mentioned above, exceeded both in delicacy and in trustworthiness the test depending upon the " spiring " of the full bright flame of the safety-lamp. It was further concluded that under the ordinary conditions of the coal-mine the spiring-test was neither a practical nor a trustworthy one.

CHAPTER VI.

DETECTION AND MEASUREMENT OF CARBONIC OXIDE IN THE AIR.

Introductory.—Carbonic-oxide gas acts as a poison when it is inhaled into the lungs. Even when this gas is present in the atmosphere in very small proportion, it renders the air dangerous. When air containing as little as 0.2 per cent. of the gas is breathed for about an hour, it produces a dangerous effect; while even 0.05 per cent. can lead to slight symptoms of poisoning, which are intensified by any physical exertion.

Sources of Carbonic Oxide in the Air.

This gas may be introduced into the atmosphere by the combustion of substances containing carbon, if the products are incompletely burnt or oxidised. Thus carbonic oxide is formed when a coal-gas flame is insufficiently supplied with air, or when the complete combustion of the flame is checked by contact with a cold surface.

The use of coal-gas flames, for the purposes of heating, cooking, and of boiling, leads to the formation of carbonic oxide, if the flame itself plays against the surfaces to be heated.

The gas is therefore usually formed in large quantity during the use of geysers and slow-combustion stoves, and is one of the products of any furnace in which the admission of air is not arranged so as to properly and completely burn the fuel.

For similar reasons carbonic oxide is a frequent product of explosions of coal-gas or of firedamp. It appears to be formed in largest quantity in colliery explosions, when

coal-dust is mingled with the air and plays a part in the explosion.

This gas is formed in several other ways in the coal-mine. It is the principal gaseous product of the firing of the cheap gunpowder known as "blasting-powder." It is produced by the explosion of the various forms of nitro-cotton ; and it seems to be invariably formed during the burning of a coal-seam and by a " gob-fire."

Carbonic oxide is also an important constituent of many forms of gaseous fuel. It is contained in coal-gas, and in producer-gas, and is present in still larger proportion in Dowson-gas, while it constitutes nearly one-half of water-gas.

There are accordingly many possible sources of carbonic oxide in the air. If the gas escapes into the open air, it is usually diluted so rapidly and largely that there is little risk incurred by breathing the surrounding air, except in the immediate neighbourhood of the escape. If, on the other hand, the gas escapes into air which is more or less stagnant and confined, poisoning may be rapidly produced by breathing the air.

Disastrous results have followed from breathing the air of a room into which unburnt coal-gas has escaped ; much more rapidly fatal results have been caused by inhaling air which has become mixed either with coal-gas enriched with water-gas, or with water-gas itself; while in the coal-mine poisoning by carbonic oxide, which has been formed during an explosion of firedamp and coal-dust, from burning coal, or from a gob-fire, is of no uncommon occurrence.

Poisonous Action of Carbonic Oxide.—This gas is rapidly absorbed by the hæmoglobin or coloured substance in the corpuscles of the blood. It is then retained with considerable tenacity, and therefore gradually accumulates in amount as more air containing the gas is taken into the lungs. It is hence a cumulative poison, and this is the reason why it is dangerous even when the proportion present is very small. Its effect is only slowly removed when

pure air is breathed, the blood requiring several hours to part with the gas which it has absorbed. Carbonic oxide seems to act specifically by preventing the blood from absorbing the oxygen necessary for maintaining the vigour of the organism.

Since the gas is absorbed by the blood, it is by the examination of blood that the presence of carbonic oxide can be most readily detected and demonstrated in the air, as will be hereafter explained. Using these methods of detection, Dr Haldane has shown that probably carbonic oxide is usually the constituent of "after-damp" which causes fatal results.

Symptoms of Poisoning.—The most recent experiments made by Dr J. S. Haldane (*Journal of Physiology*, vol. xviii., pp. 430, 463) show that the symptoms produced in man by the breathing of air containing carbonic oxide are simply those which result from the blood being deficient in oxygen. These symptoms are undoubtedly caused by the absorption of the carbonic oxide by the corpuscles of the blood, since the corpuscles are thus prevented from absorbing the necessary amount of oxygen. Accordingly, the same symptoms, as those caused by breathing air containing carbonic oxide, may be produced by breathing air which has been much reduced in pressure, as is done in mountain and balloon ascents, or by breathing air at ordinary pressure which contains a reduced percentage of oxygen. The recovery from carbonic-oxide poisoning by breathing fresh air is, however, much more slow than from air deficient in oxygen, owing to the tenacity with which the blood retains the carbonic oxide.

The symptoms caused by carbonic oxide are palpitation, feeling of fulness in the head and giddiness, together with a tendency to impairment of the senses and loss of power over the limbs. The breathing is rendered only slightly more rapid. These symptoms do not occur in the earlier stages of the poisoning when one is at rest, but only when some physical exertion is made.

During rest the symptoms are first felt when the blood is one-third saturated with carbonic oxide, and is therefore deficient in oxygen to the extent of one-third. When the blood is in this condition, however, physical exertion rapidly induces serious symptoms.

Poisonous Proportions.—It was noted that the presence of only 0.05 per cent. of this gas in the air was sufficient to produce slight symptoms during exertion, after the air had been breathed for about an hour and a half. This proportion of gas led to no dangerous results. It appeared that in this, as in other experiments, the maximum amount had been absorbed by the blood after the air had been breathed for about one and a half to two hours.

When the percentage of carbonic oxide in the air reaches 0.2 per cent., the air becomes distinctly dangerous. The effect is, as usual, much more pronounced during exertion than during repose. But after breathing air containing 0.2 per cent. of the gas during repose for about an hour, the powers of walking, writing, thinking, and seeing are distinctly impaired.

Air containing as much as 1.3 per cent. of this gas has been breathed for a shorter time, but it would undoubtedly cause death if breathed for long.

About 0.2 per cent. was found to cause death in the case of mice; and there is no reason to doubt that the same proportion, if breathed for several hours, would be fatal to a man.

Comparing a man with a mouse as regards the rapidity with which symptoms of poisoning from carbonic oxide appear, it was found that when both man and mouse breathed the same atmosphere, the mouse showed the symptoms of poisoning in one-twentieth of the time which was required for their appearance in the man. This was doubtless due to the greater respiratory energy of the mouse.

The Mouse-Test.—The most satisfactory and practical

means of insuring against danger from unconsciously breathing air containing carbonic oxide depends upon the above fact, that a mouse is much more rapidly sensitive than a man to the poisonous action of the gas.

Dr Haldane suggests that when a man must enter an atmosphere which may contain a poisonous proportion of carbonic oxide, he should carry with him a mouse confined in a wire cage freely open to the air. The mouse will become insensible and unable to move, by breathing air containing carbonic oxide, in about one-twentieth the time necessary to produce these effects upon a man. Hence by watching the mouse a warning is given in ample time to enable the man to escape from danger with his senses and muscular power unimpaired.

Even when as large a proportion as 0.5* per cent. of carbonic oxide is present in the air, the man, by constantly watching the mouse, will have twenty minutes for escape from the deadly atmosphere before he loses power of retreat.

Dr Haldane is to be congratulated upon furnishing a means of enabling explorers to enter air containing "afterdamp," or in which coal is " heating " or burning, without proceeding so far as to incur personal danger ; and the application of the test appears to be legal, since it is known to cause no pain to the mouse.

The Hydrogen-Flame Test.—Carbonic oxide, even when it is present in dangerous proportion in the air, is not detectable by the flame of a candle or of an alcohol lamp or oil-lamp. It should be understood that the hydrogen-flame will detect small proportions of carbonic oxide in the air. It was found that the standard hydrogen-flame gave a cap 0.5 inch in height in air containing 0.25 per cent. of carbonic oxide, and that the cap increased regularly in

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* In Dr Haldane's original paper this number was unfortunately printed 5 in mistake for 0.5.

height as the percentage of carbonic oxide was augmented. No one could fail to see and measure these caps, and the non-appearance of a cap may be taken to indicate that the atmosphere is not of a rapidly poisonous nature.

If it is known that a cap, seen over the hydrogen-flame, must be due to carbonic oxide, and not to any other inflammable gas in the air, the hydrogen-flame test for carbonic oxide would yield satisfactory results, and would serve as a warning against danger.   But unfortunately carbonic oxide is rarely unaccompanied by other inflammable gases.   Now the flame-cap given by this gas is indistinguishable from the caps yielded by other gases.   Hence there is not only a possibility of ascribing a cap which is actually produced by some non-poisonous inflammable gas to carbonic oxide; but there is also a probability that the proportion of carbonic oxide, when that gas is known to be present, will be much overestimated, since the cap which is seen may be only partially due to carbonic oxide, and may be augmented by the presence of other inflammable gases.

These causes would evidently lead to an overestimation of danger.   On the other hand, if the gas measured by the cap is of known composition, such as coal-gas or water-gas, the amount of carbonic oxide may be calculated after the total percentage of inflammable gas has been estimated by the cap.

There is, however, another reason why the hydrogen-flame test must not, under ordinary circumstances, be relied upon for detecting and measuring dangerous proportions of carbonic oxide.

The danger due to the presence of minute proportions of carbonic oxide in the air is largely increased if the air is also at the same time deficient in oxygen.   Now it will almost invariably be true that if carbonic oxide is present in the air, other gases will accompany it, and will tend to dilute the air, and thus to reduce the proportion of oxygen.

There can be no doubt that while fresh air containing 0.05 per cent. of carbonic oxide produces only a slight

effect upon man, air in which the oxygen has been reduced to 10 per cent., and which is also mixed with 0.05 per cent. of carbonic oxide, will produce a fatal effect when it is breathed.   Neither this reduction of the proportion of oxygen nor the presence of the carbonic oxide would be shown by the hydrogen-flame.

Taking the case of the atmosphere of the coal-mine as an instance, it has been shown by Haldane that large amounts of "black-damp" are constantly escaping from the coal into the air of the mine, and that this black-damp is a mixture of 85 to 90 per cent. of nitrogen with 15 to 10 per cent. of carbonic acid (Haldane, *Proc. Royal Soc.*, lvii. 249, 1895 ; Haldane and Atkinson, *Trans. Fed. Inst. of Mining Engineers*, 1895, p. 549).

Now the admixture of this black-damp with the air would have two separate effects in increasing the poisonous effect of any trace of carbonic oxide simultaneously present in the air.   It would act, as is described above, by reducing the proportion of gas in the air.   But the carbonic acid, if it exceeded 3 per cent., would also increase the rapidity of the breathing, and would thus hasten the absorption of carbonic oxide by the blood.

Increased rapidity of respiration and more rapid absorption of carbonic oxide would further result from muscular exertion.   Hence the presence of diluent but non-poisonous gases may easily make a non-poisonous proportion of carbonic oxide dangerous.   Similar reductions of the proportion of oxygen in the air would also occur in the air of the coal-mine from the introduction of firedamp and from other causes.

It is evident also that the introduction of carbonic oxide into the air by an escape of coal-gas, water-gas, furnace-gas, producer-gas, or in any of the ways previously specified, would be accompanied by the introduction of other diluent gases.   The poisonous action of the carbonic oxide would be thereby increased.

The above considerations will prove the value of the

" mouse-test." All the causes which enhance the danger to man arising from breathing carbonic oxide would in a similar degree increase the danger to the mouse. Accordingly, the mouse-test indicates not merely the minimum dangerous percentage of carbonic oxide, but the minimum quantity which is actually dangerous in the particular atmosphere which is then being breathed.

The flame-cap test, although it is useful for indicating the presence of poisonous proportions of carbonic oxide or of mixtures of known composition which contain the gas, would frequently give misleading results as an indication of danger from carbonic oxide; and this would be true of any test which deals only with the detection and measurement of the carbonic oxide without taking into account the proportions of oxygen and of carbonic acid which are also present in the air.

There are, however, circumstances in which it is desirable to detect and estimate carbonic oxide in the air. Several methods are available which deal with this gas only to the exclusion of all other gases. These will undoubtedly prove important and valuable under certain conditions.

Detection of Carbonic Oxide by means of Blood Solution.—One of the most convenient methods for detecting carbonic oxide in the air consists in shaking up some diluted blood with the air. The blood, if it is sufficiently diluted, furnishes a brownish-yellow liquid, and this colour changes to pink when the liquid has absorbed carbonic oxide.

Hence the presence of carbonic oxide in the air is easily demonstrated by diluting some "whipped" blood about one hundred-fold with water, reserving a portion of this liquid for comparison, and shaking another equal portion in a bottle with the air to be tested. The two portions of liquid are then poured into clear glass test tubes, half an inch in diameter. On looking through the tubes at a white surface, illuminated by daylight or other *white* light, the presence of carbonic oxide in the air under examination is

indicated by the appearance of a *pink tint* in the blood which has been shaken with the air.

This tint is easily seen by comparison with the liquid which has not been exposed to carbonic oxide.

For this qualitative test a large drop of defibrinated blood, or of human blood freshly drawn by pricking the finger, may be diluted to 10 cubic centimetres with water. The solution is divided into two equal portions. One portion is shaken gently for ten minutes in a bottle containing about 100 cubic centimetres of the air to be tested. The tints of the two portions are then compared, by being held against a well-lighted white surface.

It is possible to detect by this method of Dr Haldane's as small a quantity as 0.01 per cent. of carbonic oxide in the air. It therefore considerably exceeds in delicacy the examination of the blood for carbonic oxide by means of the spectroscope (Vogel, *Berichte d. Deutschen Chem. Gesell-schaft*, x. 792 and xi. 235), which does not detect less than 0.25 per cent. The method even surpasses in delicacy Hempel's modification (*Zeitschrift. f. Anal. Chemie*, xviii. 402), which detects a minimum of 0.06 per cent.

Estimation of Carbonic Oxide by means of Blood Solution.—Dr Haldane has adapted his method of detecting carbonic oxide in the air to the estimation of its amount when it is present in small proportions. He bases the estimation on the fact that the intensity of the pink tint produced in diluted blood by shaking it with air containing carbonic oxide increases as the percentage of carbonic oxide present in the air increases. It is therefore possible to infer the percentage of carbonic oxide, which was originally present in the air with which the diluted blood has been shaken, by measuring the intensity of the pink tint.

The intensity of the pink coloration may be judged with considerable accuracy by mere inspection, after some experience has been gained in the method. But Dr Haldane considers that the most accurate measurement of the in-

tensity is made by bringing up the pink tint of the blood to the same intensity, as that of another portion of the same blood which has been saturated with carbonic oxide. For this purpose dilute pink solution of carmine of known strength is added in measured quantity to the blood solution used in the test, until its colour matches that of the blood solution which has been saturated with carbonic oxide.

The carmine solution is made by mixing 1 gramme of pure carmine with a few drops of ammonia solution in a mortar, and then with 100 cubic centimetres (c.c.) of glycerine. This glycerine solution is preserved in a bottle. The standard test solution should be prepared freshly, just before it is used, by diluting 5 c.c. of the glycerine solution to 500 c.c. with water. It will keep for some time if light is excluded.
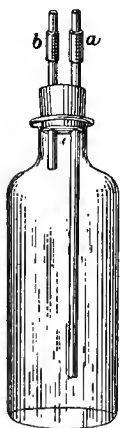

The blood solution is prepared by diluting defibrinated ox-blood one hundred-fold with water, or by diluting two large drops of blood, drawn by pricking the finger, to 20 c.c.

The sample of air to be tested is collected in a bottle of about 200 c.c. capacity (Fig. 41). The bottle is fitted with a doubly-perforated rubber cork, through which pass two glass tubes (a b). The upper ends of these glass tubes can be closed by short lengths of rubber tubing into which small pieces of glass rod are inserted. The bottle is filled with the air to be tested, by passing the air through the bottle. This is effected by opening both the tubes, and either sucking the air out through b, or blowing it by bellows

FIG. 41.—BOTTLE through a.
FOR COLLECTING
AIR-SAMPLE.   The process is continued until 2 or 3 litres of the air have passed through the bottle. The tubes are then closed by the rubber stoppers. Five c.c. of the blood solution are then drawn up into a pipette, and the point of the pipette is inserted into one of the

rubber tubes of the bottle immediately after withdrawing the stopper. By pinching up the rubber joint of the other tube, sufficient air is then allowed to escape from the bottle to permit the liquid to flow in. The pipette is removed, and the stopper is at once inserted into the rubber tube. The bottle is now covered with a cloth, or taken into a darkened room, and is shaken for ten minutes to promote the absorption of carbonic oxide by the blood. It is necessary to protect the blood solution, containing carbonic oxide, from light, else the results obtained are too low.

The solution is then removed from the bottle by means of a pipette into a test-tube, about 0.5 inch in diameter and capable of holding 12 c.c. Into a second precisely similar tube 5 c.c. of the original blood solution are poured. Into a third tube of the same dimensions 5 c.c. of the blood solution, which have been saturated with carbonic oxide, are introduced. This liquid is saturated with carbonic oxide by pouring it into a small flask or bottle, sweeping out the air by a stream of coal-gas, and shaking the liquid with the gas gently for two or three minutes.

The tints of the liquids in the three tubes are then compared by looking across them at a white surface well lighted by white light. If more than 0.01 per cent. of carbonic oxide was present in the air, the portion of blood solution in the first tube which was shaken with the air will appear more pink than the solution in the second tube which is free from carbonic oxide. If more than 3 per cent. of carbonic oxide was present in the air, the colour of the liquid in the first tube will be equal to that of the saturated portion in the third tube. It is not possible to judge the colour with accuracy when more than 0.7 per cent. of carbonic oxide was present in the air.

The degree of pink colour of the liquids may be estimated by inspection, and the proportions of carbonic oxide in the air may be inferred if the proportion is between 0.01 per cent., which causes no danger, and 1 per cent., which is extremely dangerous.

For this purpose the percentage of carbonic oxide is roughly judged by comparing the pink colour of the test liquid in the first tube with that of the saturated liquid in the third tube, and with that of the fresh blood solution in the second tube. The percentage saturation of the blood is thus judged, and the corresponding percentage of carbonic oxide in the air is then found from the following table :—

Percentage Saturation of the Blood Solution.			Percentage of Carbonic Oxide in the Air.
10	..	...	0.012
20	...	...	0.025
30	...	...	0.04
40	...	...	0.06
50	...	...	0.08
60	...	...	0.12
70	...	...	0.19
80	...	...	0.30
90	...	...	0.70

If the percentage of carbonic oxide is to be measured with greater accuracy by an inexperienced observer, the colour of the 5 c.c. of the fresh blood solution in the second tube is brought carefully up to that of the first tube, and finally to that of the saturated blood solution in the third tube by adding to it the carmine solution, little by little, from a graduated burette or pipette, and noting the volume thus added.

The volume of the carmine solution required in each instance is carefully noted down.

The method of calculating the percentage saturation of the blood with carbonic oxide from the results thus obtained will be understood from the following example :—

In a particular estimation 5 c.c. of the original blood solution required to be mixed with 6.2 c.c. of the carmine solution, in order to bring its colour up to the saturation tint. The proportion of the carmine solution to the whole liquid mixture was therefore 6.2 to 6.2 + 5, or 11.2.

Five c.c. of the original blood solution required to be mixed with 2.2 c.c. of the carmine solution in order to bring its colour up to that of the blood solution which had been shaken with the air. The proportion of the carmine solution to the whole liquid was therefore 2.2 to 2.2 + 5, or 7.2.

Accordingly the percentage saturation of the blood, occasioned by shaking it with the air to be tested, is equal to

$$\frac{2.2}{7.2} \times \frac{11.2}{6.2} \times 100 = 55.2 \text{ per cent.}$$

It should be stated that in order to obtain accurate and corresponding results, the blood solution must be freshly prepared by dilution with water on the day of each experiment, since the diluted liquid changes when kept. The strong glycerine solution of carmine and the undiluted blood, however, will keep for a long time in stoppered bottles without undergoing change.

It is further noteworthy, that the results are only comparable, when the percentage of oxygen in the air to be tested is nearly normal. When the deficiency of oxygen in the air amounts to 5 per cent., the indicated percentage of carbonic oxide will be about a third too high, thus 0.15 will be found instead of 0.11.

Since the blood seems to absorb the carbonic oxide and the oxygen in the air in the proportion in which each is present in the air, a rough correction may be applied by estimating the oxygen, and then reducing the percentage of carbonic oxide found, in the same proportion as the oxygen is deficient. Thus if the oxygen in the air amounts to only 14 per cent., it is deficient to the extent of one-third, since 21 per cent. is the normal percentage.

If carbonic oxide has been estimated in such air, and 0.3 per cent. has been found, the actual percentage will therefore be approximately $0.3 - \dfrac{0.3}{3} = 0.2$ per cent. This correction cannot be applied if the carbonic oxide is present in less proportion than 0.01 per cent.

When there is more than 0.5 per cent. of carbonic oxide present in the air, or when a gaseous mixture is being used which contains but little oxygen, the above method of estimation only yields correct results after the gaseous mixture to be tested has been suitably diluted with air. Thus coal-gas would require to be diluted with air to forty or fifty times its volume, if the carbonic oxide in it is to be correctly estimated by the above method.

The delicacy of the test may be increased twenty-fold by absorbing the oxygen from the air before applying the above method for estimating the carbonic oxide.   By this means it is possible to detect and estimate as little as 0.001 per cent. of carbonic oxide, or 0.02 per cent. of coal-gas and 0.003 per cent. of water-gas.

Up to 60 per cent. saturation of the blood with carbonic oxide, an error of 5 per cent. in the actual quantity of the carbonic oxide estimated may occur.   Above 60 per cent. saturation, the error increases.   In other words, the method must be looked upon as yielding accurate results with small percentages of carbonic oxide, but as being unsuitable for the accurate estimation of large percentages unless a correction is applied.   It therefore usefully supplements the following method, which is accurate for larger percentages, but is not suitable for estimating less than 0.5 per cent.

Detection and Estimation of Carbonic Oxide by means of Cuprous Chloride Solution.—A solution of cuprous chloride serves as an absorbent of carbonic oxide, but this liquid also absorbs oxygen, and to a lesser extent carbon dioxide.   Hence in using this method of estimation it is necessary to absorb first the carbon dioxide and oxygen from a known volume of the mixture ; carbonic oxide may then be absorbed from the remaining gas.   By accurately reading the volume of the gaseous mixture before and after the absorption of the carbonic oxide, the volume of this gas which was present in the original volume of the

gaseous mixture is obtained, and this may be expressed in percentage proportion.

The most convenient form of apparatus for carrying out this process of estimation is the Hempel gas-apparatus. A full description of its use will be found in works on gas-analysis. Such an account will be found in Clowes and Coleman's "Quantitative Analysis," on pages 435-451.

This method of estimating carbonic oxide is suitable for all proportions of the gas exceeding about 0.5 per cent. The process is therefore supplementary to that of Dr Haldane by blood solution, which has been already described.

APPENDIX TO CHAPTER VI.

DETECTION OF HYDROGEN SULPHIDE, OR SULPHURETTED HYDROGEN.

This gas is occasionally present in the air of the coal-mine. It is also generated in large amount in certain chemical processes. It is extremely poisonous, when inhaled in large quantity in the air. If breathed in a nearly unmixed condition, it rapidly produces unconsciousness and utter helplessness ; and if breathed for a long time mixed in small proportion with air, it produces serious disturbance of health.

The very pronounced and foul odour of the gas usually leads to its presence being readily detected by the sense of smell. It is easily detected also by its power of staining paper moistened with solution of lead acetate (sugar of lead) dark brown. The test-paper for detecting the gas is best prepared by adding potassium hydrate (caustic potash) solution to lead acetate solution in sufficient quantity to redissolve the precipitate which forms at first, and thus to render the liquid clear. Paper wetted with this liquid becomes intensely black when it is exposed to air containing hydrogen sulphide gas.

Methods for finding the volume of this gas present in air are given in books on gas-analysis, and will be found in Clowes and Coleman's " Quantitative Analysis."

CHAPTER VII.

ATMOSPHERES WHICH EXTINGUISH FLAME, AND WHICH ARE IRRESPIRABLE.

An ordinary flame may be extinguished by the presence in the air in sufficient quantity of any gas which does not support combustion. The extinctive gas may itself be either combustible or incombustible.

The appearance presented immediately before the extinction of the flame will, however, usually serve to indicate whether extinction has been caused by a combustible or by an incombustible gas. The gas, if combustible, will usually itself be kindled in the neighbourhood of the flame, and the appearance of this surrounding flame in the air will prove the presence of an inflammable gas. The non-combustible gas, on the other hand, will simply quench the flame without the appearance of inflammation around it.

It should be remembered, however, that even when the air contains a quantity of incombustible gas insufficient to extinguish flame, the flame may nevertheless be extinguished if a small quantity of inflammable gas is also present. This gas will not only exclude the oxygen necessary for maintaining the flame, but will also by its own combustion reduce the amount of oxygen around the flame, and will frequently supply products, which, by aiding the extinctive mixture already present in the air, will hasten the extinction of flame.

In connection with gas-testing, the extinction of flame is of interest, since it is usually stated that air in which a flame will burn may be safely breathed, while air which

extinguishes a flame is dangerous to be breathed or is actually irrespirable.

Both these statements require considerable qualification, and for the following reasons :—

1. There are many poisonous gases or vapours the presence of which in dangerous quantity in the air is not indicated by an ordinary luminous flame.

Carbonic oxide gas may come into frequent practical consideration in the air, since it is introduced in the form of water-gas, or as a product of an explosion or combustion where carbon has been incompletely burnt ; in the coal-mine it is an invariable product of the cheap gunpowder known as "blasting-powder," as well as of other more modern explosives.

As has been already shown, the delicate hydrogen-flame test will detect the presence of this gas ; a luminous flame, however, would assuredly not find a small, but still poisonous proportion, of carbonic oxide. The flame would continue to burn unchanged in the presence of small amounts of this gas. The only difficulty in detecting carbon monoxide by the hydrogen-flame test depends on the fact that the flame-cap is indistinguishable in appearance from that yielded by other inflammable gases.

2. A second reason why the extinction of a candle-flame by the air does not prove the air to be irrespirable is that an atmosphere which extinguishes an ordinary oil-flame or candle-flame may be perfectly suitable for respiration.

An instance is furnished by the air expired from the lungs or by the atmosphere produced by burning a candle-flame in a confined portion of air sufficiently long to extinguish the flame. These atmospheres at once extinguish a candle-flame or oil-flame, but are respirable not only without danger but even without inconvenience.

Several independent series of experiments showed that an oil-flame or a candle-flame was extinguished by atmospheres of the following percentage composition :—

PERCENTAGE COMPOSITION OF ATMOSPHERES EXTINCTIVE
OF A COMMON OIL OR CANDLE FLAME.

	Oxygen.	Nitrogen.	Carbonic Acid.
1. Air expired from the lungs (average)	16.15	79.9	3.95
2. Air in which a candle-flame or oil-flame had burnt until it was extinguished	16.05	80.80	3.15
3. Mixture of air with nitrogen	16.40	83.6	...
4. Mixture of air with carbon dioxide	18.06	67.94	14.00
5. Fresh air (for comparison)	20.9	79.06	0.04

Now each of these mixtures is respirable. The first three, produced respectively by breathing, by burning, and by addition of nitrogen, may in fact be breathed by a healthy person without any noticeable effect being produced upon them. The fourth mixture which is obtained by adding carbon dioxide to the air, would cause distressed breathing and possibly insensibility, but would not be fatal until it had been breathed for at least twelve hours.

Hence it will be seen that while the extinction of an ordinary flame should raise suspicion as to the suitability of air to support life, since it may be due to an atmosphere unsuitable to be breathed, yet the extinction of a flame furnishes no proof that the atmosphere is at all unfit for respiration. On the other hand, an atmosphere in which the flame burnt unchanged may be rapidly fatal, since a poisonous quantity of carbonic oxide may be present. Suspicion would naturally be aroused if the extinction of the flame was due to carbon dioxide which had been added to the air or if carbonic oxide might be present.

It is important that these facts should be borne in mind, else rescue parties in the coal-mine, or those engaged in necessary work in an impure atmosphere, might be deterred

from carrying out their indispensable or humane duties by
the extinction of the lamp or candle flame. The probable
cause of extinction should be ascertained. If the air had
been rendered extinctive by respiration or by ordinary com-
plete combustion only, no danger is proved to be present
by the extinction of the flame.

In this connection it is noteworthy that the extinction of
a coal-gas flame furnishes a much more trustworthy indica-
tion of the dangerous condition of the air than the extinction
of the candle-flame or oil-flame does. A gas-flame will
continue to burn in an atmosphere which extinguishes the
flame of a candle or oil-lamp, but it is extinguished by an
atmosphere which is not respirable with safety.

The hydrogen-flame is of all known flames the least liable
to extinction by air which is deficient in oxygen, or which
has been mingled with carbon dioxide. The combustion of
the hydrogen flame is maintained in an atmosphere which is
immediately extinctive to all other flames.

This property of the hydrogen-flame renders it invaluable
as an auxiliary flame in a safety-lamp. If it is burnt beside
the oil-flame within the lamp, the extinction of the oil-flame
indicates that a doubtful atmosphere is being entered, from
which it may be prudent to withdraw. The hydrogen-
flame will meanwhile continue to burn, and will not only
serve to rekindle the oil-flame when a purer atmosphere is
entered, but will also enable an indication to be obtained of
the attainment of a purer atmosphere by the reappearance
of the oil-flame.

The safety-lamp with hydrogen attachment, which has
been already described (p. 58), has been used in the above
manner with the greatest ease and satisfaction. It has
enabled its bearer to retreat from a bad atmosphere, and to
have again the advantage of a lamp to light him, while his
companions, who had no auxiliary hydrogen-flames, were
left with lamps entirely extinguished.

If it is necessary to penetrate an irrespirable atmosphere,

the Fleuss apparatus (*Trans. N. Engl. Inst.*, xxxi. 197-203) may be employed for supplying oxygen for respiration; the hydrogen-flame will then maintain the combustion within the lamp as is described above. Fuller details are given on pages 156-167 respecting the composition of the atmospheres which are extinctive to flames.

As regards the respirability of air changed in composition by respiration or combustion, or by the admixture of other gases, some general statements may be made which are founded on the information furnished by standard physiological treatises, and by the published papers of Dr J. S. Haldane and J. Lorrain Smith, entitled "The Physiological Effects of Air Vitiated by Respiration," and "The Toxic Action of Respired Air," in the *Journal of Pathology and Bacteriology*, October 1892 and February 1893.

It appears that the reduction of the proportion of oxygen in the air to 12 per cent. causes the beginning of symptoms of accelerated respiration. A reduction to 8 per cent., without the introduction of any other gas in sufficient quantity to produce any physiological effect, usually renders the breathing decidedly rapid and laboured. The proportion of oxygen cannot be reduced below 7 per cent. without danger to some individuals.

On the other hand, the introduction of carbon dioxide in a larger proportion than 5 per cent. causes accelerated respiration and headache. The presence of carbon dioxide in a proportion reaching 10 per cent. renders respiration very rapid and laboured, and produces extreme distress, and 12 to 15 per cent. may cause insensibility. Such an atmosphere is, however, not fatal for many hours, and a person who has breathed it recovers when exposed to fresh air.

Air containing from 3 to 4 per cent. of carbon dioxide produces the above effects slightly.

Carbon dioxide frequently collects in wells and pits by escaping from the surrounding soil. In coal-mines also a

mixture of nitrogen and carbonic acid, known as "black-damp," escapes into the air in large quantity. It will be evident, therefore, that a test for the proportion of carbon dioxide in air is often necessary.

DETECTION AND MEASUREMENT OF CARBON DIOXIDE IN THE AIR.

By the Hydrogen-Flame.—Observation of a hydrogen-flame, which is introduced into air containing added carbon dioxide, shows that the presence of this gas causes the flame to undergo a marked alteration of colour.

Pure hydrogen-gas when burnt in fresh air gives a flame of a faint reddish-purple colour.

In the presence of carbon dioxide or of diminished oxygen this colour tends to become bluish, and if sufficient carbon dioxide is present, the colour of the flame ultimately becomes pure blue. This change of colour serves as a rough means of detecting carbon dioxide in the air when it is present in proportions which are far below those which give rise to danger to life.

It has been found that if the air contains over 2 per cent. of carbonic acid gas the hydrogen-flame becomes blue. Large quantities of this gas are indicated by the hydrogen and oil flames as follows :—In the presence of 10 per cent. of the gas the oil-flame begins to diminish in size, and the hydrogen-flame changes from a reddish colour to a blue-grey. In the presence of 15 per cent. of the gas the oil-flame is extinguished, and the hydrogen-flame becomes more decidedly blue.

This change of colour in the hydrogen-flame progresses as the proportion of the gas increases. With 30 per cent. of carbonic acid the 0.8 inch hydrogen-flame also enlarges to 1.1 inch.

It appears that diminution of the proportion of oxygen in the air by any means will also cause a similar change of colour of the hydrogen-flame ; hence the test is not an

absolute one for carbon dioxide in cases where the oxygen may be reduced in other ways.

By observing the Turbidity of Lime-Water.—
Angus Smith suggested a means of measuring carbon dioxide in the air, by observing the amount of the air which is necessary to cause a standard turbidity in lime-water.   He suggested the passage of air in a stream of bubbles through a measured quantity of lime-water in a bottle, the air being
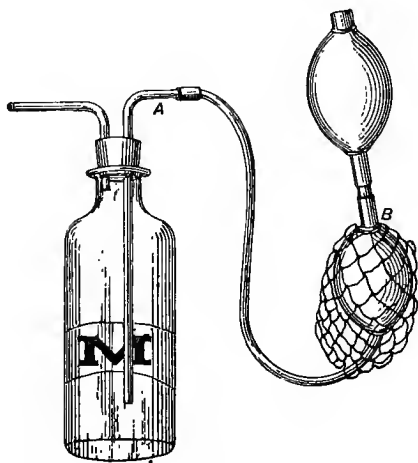

Fig. 42.—Apparatus for Measuring Carbonic Acid in Air.

passed until the lime-water becomes so turbid that a printed letter on the back of the bottle just becomes invisible when it is looked at through the lime-water.

Very satisfactory results were obtained by squeezing a rubber-ball with an automatic valve, such as is used for medical purposes.   The ball B was attached to the tube A of the bottle, as is shown in Fig. 42, and lime-water was poured in until it reached the mark on the bottle.   The letter M was pasted on the back of the bottle.   The air

was then forced through the lime-water at a uniform rate by means of the valve-ball until the letter M just ceased to be visible owing to the turbidity of the lime-water.

The relative volumes of different samples of air, which are necessary to cause the standard turbidity in the lime-water in different tests, will be proportional to the number of times which the ball has been squeezed; and the amount of carbonic acid in the air will be inversely as the number of times the ball is squeezed. A few preliminary experiments with air containing a known percentage of carbonic acid will serve as a basis on which the percentage of carbonic acid can be calculated from the results of observation.

Thus in a particular experiment it was found that the ball had to be squeezed twenty-three times in forcing air containing 5 per cent. of carbonic acid through the lime-water before the turbidity rendered the letter invisible. In another case the ball was squeezed eight times before the same degree of turbidity was caused in the same volume of lime-water. In the latter case one-third the volume of air only was required to cause the same turbidity. Hence the air contained three times as much carbonic acid as in the first experiment, or 15 per cent.

By Observing the Loss of Colour of an Indicator in presence of Lime-Water.—A method of determining the point of saturation by carbonic acid of a constant volume of dilute lime-water is described by Dr Cohen (*Chemical News*, September 1894, p. 111). Dilute lime-water is prepared by making 10 c.c. of saturated lime-water up to a litre with distilled water. The indicator is prepared by dissolving 0.2 gramme of phenol-phthalein in 100 c.c. of water.

For the experiment a 24-ounce stoppered bottle is filled with the air to be tested, by blowing the air through it for some time with bellows. Ten c.c. of the dilute lime-water and 0.3 c.c. of the indicator solution are then quickly introduced into the bottle, which is immediately stoppered.

The bottle is then constantly shaken so as to expose the red liquid to the air in the bottle, the time during which the shaking has to be continued in order to just remove the red colour being noted by the seconds-hand of a watch.

If the colour disappears immediately, the air is highly charged with carbonic acid. If the change requires three minutes, there is about twice the normal amount of carbonic acid. Fresh air requires to be shaken about seven minutes to destroy the colour. If ninety seconds' shaking are necessary the amount of carbonic acid is about four times that found in fresh air.

Thin sealed glass tubes containing the lime-water and indicator for each test can be purchased. A tube is dropped into the bottle and broken for the test.

Measurement by the Hempel Apparatus.—The proportion of carbonic acid may be determined by the preceding methods *in situ*. Another method which cannot be generally employed on the spot involves the use of a laboratory apparatus. A simple form of apparatus of this kind is the Hempel gas-apparatus. A description of the construction and method of using this apparatus will be found in works on volumetric analysis. Reference may be made to Clowes and Coleman's "Quantitative Analysis," pages 435-451.

APPENDIX TO CHAPTER VII.

The Composition of Atmospheres which Extinguish Flame. (Proc. Roy. Soc., vol. lvi.)

By Frank Clowes, D.Sc.

Introductory Remarks.—A study of the experiments which have been made to determine the composition of atmospheres, which act extinctively upon flame, shows that in many cases the atmosphere under examination was in contact with water. The solvent action of water on the carbon dioxide present seems in such cases likely to disturb the composition of the mixture. In other cases, only the proportion of oxygen in the extinctive atmosphere was noted, and the nature of the diluent gas or gases was not taken into consideration.

Experiments were also limited to the flames of a few combustible substances, or where a wider range of different flames were tried, the results reported were only of an approximate and relative nature.

The experimental work, the results of which are summarised in this communication, was undertaken in order to supplement the deficiencies referred to above, with the view of drawing further generalisations and of furnishing support to those already drawn from previous experiments.

Method of Experimenting.—The mixtures of air with the extinctive gas were made in a glass cylinder, which was closed by a ground glass plate. The capacity of the cylinder, diminished by the volume of a light xylonite ball, which was subsequently introduced, was noted.

A measured quantity of water, equal in volume to the percentage of extinctive gas to be mixed with the air, was poured into this glass cylinder. The cylinder was then closed by the plate and inverted in a vessel of water. The light xylonite ball, whose volume had previously been subtracted from the capacity of the cylinder, was then passed up, and the extinctive gas was introduced in sufficient quantity to fill the cylinder. The cylinder was then closed, and its contents were mixed by rolling the ball up and down the cylinder.

In order to test the accuracy with which any desired mixture of gases could be prepared by this method, two mixtures of air with carbon dioxide were submitted to analysis. They furnished respectively 9.8 instead of 10 per cent., and 69.7 instead of 70 per cent. of carbon dioxide.

The experimental flames used were 0.75 inch in height, and were gradually lowered into the cylinder, the top of which was finally covered by the plate. The gases were burnt from a platinum jet 1 millimetre in diameter.

The gaseous mixture was considered to be in extinctive proportions, if the flame was extinguished during its downward passage, or immediately upon attaining its lowest position in the cylinder. The mixture was considered to contain the *minimum necessary quantity* of extinctive gas, if another mixture containing 1 per cent. less of the extinctive gas allowed the flame to continue burning in it for a few seconds only.

The limiting differences between the results of repeated trials corresponded to 1 per cent. of the extinctive gas in the air.

This minimum necessary percentage of extinctive gas is recorded below in tabulated form for each of several gases.

It was considered necessary to take the *immediate extinction* of the flame as the criterion of extinctive power, since the composition of the atmosphere was rapidly affected by the combustion of the flame.

Influence of the Size of the Flame.—As a matter of convenience, the flames were in all cases set to a height of 0.75 inch. But a series of experiments was undertaken with the same flame of varying size, in order to ascertain if the proportion of extinctive gas necessary to extinguish the flame varied with the size of the flame.

The results of these experiments with flames of hydrogen and of alcohol, varying from 0.4 inch to 1.5 inch in height, show that the varying dimensions of the flame, within the wide limits included in the trials, are without influence on the proportion of carbon dioxide in the air necessary to produce extinction.

Method of Preparation of Gases Used.—*The carbon dioxide* employed for the experiments was prepared in the usual way by the action of diluted hydrochloric acid upon marble. It was washed with water, and was proved to be practically free from air.

The nitrogen was prepared by heating an aqueous solution containing potassium nitrite, ammonium chloride, and potassium dichromate. An analysis of the resulting gas proved that it contained 99.7 per cent. of nitrogen.

Results Obtained by the Experiments.—In the following table the percentage volume of added gas, which is entered, is the average of numerous closely concordant experimental results. The percentage volume of nitrogen in fresh air is taken as 21.

COMPOSITION OF AIR RENDERED EXTINCTIVE BY ADDITION OF CARBON DIOXIDE AND OF NITROGEN.

Combustible Substance Burnt.	Addition of Carbon Dioxide to Air.			Addition of Nitrogen to Air.		
	Percentage of Carbon Dioxide added.	Percentage Composition of the Extinctive Mixture produced.		Percentage of Nitrogen added.	Percentage Composition of the Extinctive Mixture produced.	
		Oxygen.	Nitrogen and Carbon Dioxide.		Oxygen.	Nitrogen.
Alcohol, absolute	14	18.1	81.9	21	16.6	83.4
Alcohol, methylated	13	18.3	81.7	18	17.2	82.8
Paraffin, ordinary lamp oil -	15	17.9	82.1	23	16.2	83.8
Colza oil with equal vol. of petroleum	16	17.6	82.4	22	16.4	83.6
Candle	14	18.1	81.9	22	16.4	83.6
Hydrogen -	58	8.8	91.2	70	6.3	93.7
Carbon monoxide or carbonic oxide	24	16.0	84.0	28	15.1	84.9
Methane or marsh-gas	10	18.9	81.1	17	17.4	82.6
Ethylene -	26	15.5	84.8	37	13.2	86.8
Coal-gas (Nottingham) -	33	14.1	85.9	46	11.3	88.7

Characteristic differences were observed between the behaviour of wick-fed flames and that of gas-fed flames, when they were introduced into an atmosphere which extinguished them. The wick-fed flames gradually diminished in size until

they vanished. The gas-fed flames, on the other hand, gradually increased in size, becoming pale and apparently lower in temperature, and then suddenly expired.

The extinction of the flame is apparently due in both cases to the lowering of its temperature. This primary cause, however, seems to operate directly in the case of the gas-fed flame, whilst in the case of the wick-fed flame it operates by gradually reducing the amount of combustible gas and vapour produced, and thus leads ultimately to the flame dying from lack of combustible material.

The large expansion of the gas-fed flame is evidently due to its attempt to obtain the necessary supply of oxygen in the diluted atmosphere by an increase of its surface.

Theoretical Considerations.—The following deductions seem to be warranted by the results arrived at in these experiments :—

1. The extinction of a flame is not determined only by the *proportion* which the inert gas bears to the oxygen of the atmosphere into which it is introduced, but also by the *nature* of the inert gas present.

2. Carbon dioxide uniformly exerts a more powerful extinctive effect upon flame than nitrogen does.

3. There is a remarkable uniformity in the proportions of inert gas which must be mingled with air in order to just extinguish wick-fed flames.

4. This uniformity does not apply to the flames of combustible gases burnt from a jet.

5. Reviewing the above results obtained with different combustible gases, it appears that the proportions of oxygen present in the atmospheres which just extinguish the flame of a combustible gas bears no relation to the amount of oxygen required for the complete combustion of the combustible gas.

With regard to the superior extinctive power of carbon dioxide over that of nitrogen, it has been stated that the greater the density of an inert gas which is introduced into air, the less will be the quantity which suffices to arrest combustion. Waldie suggests that this is due to the cooling effect which is produced upon the flame by the rapidity of diffusion of its

heated products, increasing as the surrounding atmosphere increases in density.

But it is probable that carbon dioxide also surpasses nitrogen in its extinctive effect upon flame in virtue of its higher specific heat, and because of its slower movement due to its high molecular weight and density. When the heavy gas is mingled with the air, it adds to the density of the mixture, and renders the atmosphere more sluggish in its movement towards the flame to supply the necessary oxygen.

It had been anticipated that in the presence of the hydrogen-flame, and possibly of other flames, carbon dioxide would have suffered partial deoxidation, as it is well known to do in the presence of burning magnesium vapour. No such action appeared to occur, else the above relation between the extinctive powers of carbon dioxide and nitrogen could not well exist.

The cause of the comparative uniformity of the proportion of extinctive gas required for wick-fed flames has been already hinted at. The flames are starved of combustible nutriment by the lowering of the temperature of the flame. This cause seems to operate with strikingly similar results upon the different solid and liquid combustibles.

The cause of the want of conformity to theoretical considerations in the case of the gaseous flames fed from jets is not at once apparent.

It is of practical interest to note that the introduction of a minimum of 15 per cent. of carbon dioxide into air is necessary to cause it to extinguish ordinary wick-fed flames, the oxygen being reduced by this admixture from the normal proportion of 21 per cent. to 18 per cent. For the extinction of a coal-gas flame, however, the addition of 33 per cent. of carbon dioxide is necessary, the oxygen being thus reduced to 14 per cent. The hydrogen-flame has far greater vitality, requiring the admixture of 58 per cent. of carbon dioxide with the air, and the consequent reduction of the oxygen to 8.8 per cent., before it suffers extinction. This fact is of great importance, since it shows that the hydrogen-flame in the composite miner's safety-lamp (*Proc. Roy. Soc.*, vol. lii., p. 486) may be used as an auxiliary to prevent the loss of flame when the lamp is being carried through mine-air containing large proportions of carbon dioxide.

The Proportion of Carbon Dioxide in Air which is Extinctive to Flame. (*Trans. Fed. Inst.*, vii. 419.)

By Frank Clowes, D.Sc.

Results obtained with Protected Flames.—Since the miner's safety-lamp is often used for detecting the presence of a high proportion of carbon dioxide in the air of the mine or of sinkings, a further series of experiments was undertaken, using various forms of safety-lamps instead of the naked flames. It will be noticed that the carbon dioxide in the mine-air is assumed to be discharged into the air, and not to be produced by processes of combustion or respiration, which would deprive the air of oxygen while introducing carbon dioxide.

The method of experimenting already described (p. 156) was adopted. A large cylinder of 8,248 cubic centimetres capacity was employed. The mixer consisted of two parallel thin circular discs of wood, somewhat less in diameter than the cylinder itself, and held about 1.5 inch apart by wooden pins. Deducting the volume of the mixer from the total capacity of the cylinder, the available capacity became 8,023 cubic centimetres. After the gaseous mixture had been prepared in the manner already indicated, the lamp was lowered into it by means of a string, and the cylinder was at once covered.

The extinctive effect of the products of combustion of the lamp itself, when it was allowed to burn in the closed cylinder filled with fresh air, was complete in three minutes.

The extinctive effect of a prepared mixture of air with carbon dioxide was naturally less promptly exerted upon the protected lamp-flames than upon the naked flames previously employed. The lamp carried down a certain amount of fresh air within its gauze and bonnet, and this delayed the extinction of the flame. Thus the oil-flame of the Davy lamp continued to burn for about twenty seconds in air containing 16 per cent. of carbon dioxide ; it burnt for about fifteen seconds when 18 per cent. of carbon dioxide was present ; and for about nine seconds in air containing 20 per cent. of carbon dioxide.

A benzoline-flame in a Gray lamp with top air-feed proved more sensitive, and was extinguished in five seconds by air containing 16 per cent. of carbon dioxide. A somewhat larger lamp of the same type was naturally more slowly influenced by

the extinctive atmosphere. Apparently the direct feed of air to the flame in these lamps led to a more prompt response of the flame to the influence of the external atmosphere.

In the Davy lamp the feed is not direct, the external air mingling more or less with the air within the lamp before it reaches the flame.

For ordinary safety-lamps the admixture of 16 per cent. of carbon dioxide with air may be considered to mark the lower limit of rapidly extinctive atmospheres.

The most striking result arrived at in the experiments with safety-lamps was that obtained by the composite lamp already described, in which either an oil-flame or a hydrogen-flame may be burnt at will. In this lamp the oil-flame was extinguished in thirty seconds by air containing 16 per cent. of carbon dioxide, while the hydrogen-flame required 58 per cent. of the same gas for its extinction in the same time. Accordingly when both flames were burnt simultaneously in the lamp, the presence of 16 per cent. of the extinctive gas in the atmosphere was marked by the extinction of the oil-flame. The hydrogen-flame, however, survived; and when the lamp was removed into fresh air, the hydrogen-flame at once rekindled the oil-flame upon the wick.

This experiment indicates that the hydrogen-flame in this lamp not only serves for delicate gas-testing when it is burnt alone, but that it may also serve, when occasion requires, as an auxiliary flame to prevent the loss of flame in the mine. When the miner is approaching any part of the workings where there might be risk of the atmosphere being extinctive to his oil-flame, he would burn the hydrogen-flame alongside the oil-flame.

A high proportion of carbon dioxide, approaching that which is dangerous to life, would be indicated by the behaviour of the oil-flame ; but even if that flame were extinguished, it would be possible for the miner to leave the foul air with the hydrogen-flame burning. This flame would rekindle the illuminating flame in fresh air, and would thus prevent the necessity of making a long journey in order to open the lamp and rekindle the flame in the fresh air at the pit-bottom. If the area over which the foul air extended was not large, it might even be possible to pass through it without loss of flame, and without danger to life.

The Composition of the Extinctive Atmospheres produced by Flames.   (*Proc. Roy. Soc.*, lxvii. 353.)

By Frank Clowes, D.Sc.

In a former paper (*Proc. Roy. Soc.*, vol. lvi.), the author communicated the results obtained by mingling gases, which were extinctive of flame, with air, until a flame burning in the air was just extinguished.   The gases used in the experiments were carbon dioxide and nitrogen.   Each of these gases was separately introduced into the air, and the composition of the atmosphere thus produced, which just extinguished flame, was determined by chemical analysis.

The general results arrived at were the following :—

1. Wick-fed flames require atmospheres of very similar composition to extinguish them ; while gas-fed flames require atmospheres of widely different composition.

2. Nitrogen must be added in larger proportion than carbon dioxide in order to extinguish the same flame.

3. The minimum proportion of extinctive gas which must be mingled with air in order to extinguish a flame is independent of the size of the flame.

A supplementary series of experiments has now been undertaken, in order to determine the composition of the atmosphere extinctive of each flame, which is produced by the flame itself when burning in an enclosed volume of air at atmospheric pressure.

Preliminary trials showed that in order to secure trustworthy results, the atmosphere must not be in contact with water.   It was further found necessary to avoid change of pressure in the enclosed atmosphere during the combustion of the flame.

These necessary conditions were complied with by allowing the flames to burn in a bell-jar, the bottom of which was closed by dipping into a sufficiently deep vessel of mercury.   The neck of the bell-jar was closed by a cork bearing a U-shaped mercury gauge, and a glass tube with a stopcock (Fig. 43).

While the flame was burning, the pressure of the air within the bell-jar was maintained uniform, by raising or lowering the bell-jar sufficiently to maintain the mercury levels unchanged in the pressure-gauge.   As soon as the flame was extinguished by

the atmosphere around it, the vessel was allowed to stand until
the atmosphere within had become uniform in temperature with
the external air. A portion of the gaseous mixture within the
bell-jar was then removed by means of the stopcock-tube to a
Hempel gas-burette, and was subjected to ordinary volumetric
analysis by absorption.

Each experiment and analysis was made in duplicate, and
frequently in triplicate. The results obtained were either identi-
cal or closely concordant, except in the case of methane ; but
the flame of ethylene could not be maintained under the condi-
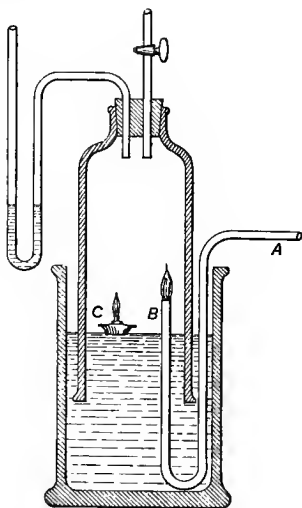tions of the experiment.

FIG. 43.—APPARATUS FOR FINDING THE COMPOSITION OF THE ATMOSPHERE
LEFT BY A FLAME.

A gas was burnt from a tube (A) passing through the mercury
and terminating in a jet (B) just above the surface of the mercury.
The liquids were burnt from wicks contained in small shallow
vessels floating upon the surface of the mercury, in a manner
similar to that adopted for the candle-flame (C).

As in the previous series of experiments (*loc. cit.*), the com-
bustible substances used were chiefly those which are burnt for
ordinary heating and lighting purposes.

The mean results are tabulated below.

PERCENTAGE COMPOSITION OF RESIDUAL AND OF ARTIFICIAL
ATMOSPHERES WHICH EXTINGUISH FLAME.

Combustible Substances Burnt.	Percentage Composition of the Residual Atmosphere in which the Flame was Extinguished.			Proportions per cent. of O_2 and N_2 in which Flame is Extinguished when introduced.	
	Oxygen.	Nitrogen.	Carbon Dioxide.	Oxygen.	Nitrogen.
Alcohol, absolute	14.9	80.7	4.35	16.6	83.4
Alcohol, methylated	15.6	80.25	4.15	17.2	82.8
Paraffin, lamp oil	16.6	80.4	3.0	16.2	83.8
Colza and paraffin	16.4	80.5	3.1	16.4	83.6
Candle	15.7	81.1	3.2	16.4	83.6
Hydrogen	5.5	94.5	...	6.3	93.7
Carbon monoxide	13.35	74.4	12.25	15.1	84.9
Methane, or marsh-gas	15.6	82.1	2.3	17.4	82.6
Ethylene (failed)	...	...	...	[13.2	86.8]
Coal-gas (Nottingham)	11.35	83.75	4.9	11.3	88.7

In the above table the results are given, which were obtained by the analysis of the residual atmospheres, in which the flame had burnt until it was extinguished. Since the proportions of carbon dioxide contained in these atmospheres are small, the composition of the artificial atmospheres consisting of nitrogen and oxygen only, in which the flames were just extinguished when they are inserted, are also stated for comparison.

It will be noticed that the general agreement in composition shown by the two classes of extinctive atmospheres, so differently produced, is well maintained; and when the conditions of the experiments are taken into account, the recent series of results are confirmatory of the general accuracy of those previously obtained.

It is noteworthy that the composition of the extinctive atmospheres produced by the flame of a candle, by an oil-flame, and by an alcohol-flame, closely corresponds with the average composition of air expired from the lungs. The composition of the last portion of air which is expired varies somewhat with the length of time during which the air has been retained in the

lungs. The following percentage composition by volume was determined :—

Analysis of Expired Air.	Oxygen.	Nitrogen.	Carbon Dioxide.
Air expired immediately after having been inhaled	17.4	78.4	4.2
Air expired about forty seconds after having been inhaled	14.9	81.4	3.7
Average composition of expired air	16.15	79.9	3.95

According to the statements published by Dr J. Haldane (*Proc. Roy. Soc.*, 6th December 1894), an atmosphere of the average composition of expired air, or of that left by the combustion of candles or lamps, although it is extinctive of the flames of candles and of lamps, can be breathed by most people without producing any distinctly noticeable effect. With some people, the increased proportion of carbon dioxide would cause the inspirations to be rather deeper than usual, but in no case would injury to health result from breathing such an atmosphere.

The statement made by the author in a previous paper (*Proc. Roy. Soc.*, vol. lvi.), that men could apparently breathe with safety an atmosphere which just extinguished the flame of a candle or of a lamp, is therefore fully borne out by the above results. This agrees with the statements made by experienced mining authorities. Accordingly the extinction of such ordinary illuminating flames cannot be considered as proof that an atmosphere is not respirable with safety.

The residual atmosphere produced by the hydrogen-flame is undoubtedly not respirable by most persons, on account of the greatly diminished proportion of oxygen which it contains. The colour of the hydrogen-flame undergoes a distinct change in colour from reddish - purple to blue as the proportion of oxygen in the atmosphere is diminished.

Since a similar change of colour is noticed when carbon dioxide is present in the atmosphere, it is probably due to the lowering of temperature of the flame : all attempts to detect

the production of carbon monoxide by this flame, when it is burning in air containing carbon dioxide, have failed.

The following conclusions may be drawn from the above results :—

1. The flames of the combustible gases and liquids which were experimented upon, have produced, at the moment of their extinction in an enclosed atmosphere, a change in the proportion of oxygen in the air which generally corresponds to that produced by preparing extinctive atmospheres by artificial mixture.

2. The flames of candles and lamps, when they are extinguished by burning in a confined space of air, produce an atmosphere of almost identical composition with that of air expired from the lungs.

3. The extinctive atmospheres produced by the combustion of the flames of candles and of lamps, and the air expired from the lungs after inspiring fresh air, are respirable with safety.

4. The extinction of an ordinary candle or lamp flame is not necessarily indicative of the unsuitability of an atmosphere to maintain life when it is breathed.

CHAPTER VIII.

DETECTION AND MEASUREMENT OF PETROLEUM VAPOUR IN THE AIR.

[By Boverton Redwood.]

Introductory.

The importance of testing the atmosphere of coal-mines has long been recognised, and it is somewhat surprising that comparatively little attention has been paid to the risk of accumulation of inflammable gas or vapour elsewhere.

Many accidents of a fatal character, and involving great destruction of property, have arisen from the ignition of an explosive gaseous mixture in the holds of vessels, as well as in other enclosed spaces, and it cannot be said that there is any lack of evidence as to the danger of allowing such a mixture to be formed.

It must therefore be admitted that a method of testing, which admits of the rapid and precise quantitative determination of inflammable gas or vapour in the air of any enclosed space, is of considerable value.

In a great many instances it is impracticable to make the test in the space itself, in the manner in which the air is tested in the workings of a coal-mine ; and accordingly the method of testing, in order to admit of general application, must be based upon the collection and subsequent examination, or upon the withdrawal and concurrent testing, of a sample of the air.

The subject came prominently under the notice of the author in connection with the occurrence of explosions in steamships which had carried crude petroleum in bulk, and

it became necessary for him and his brother, Mr Robert Redwood, in the discharge of their routine duties, to decide which of the available methods was in their judgment best suited for use in testing the atmosphere of the tanks and other spaces in such steamships after the discharge of the cargo.

An experimental investigation led them to give unqualified preference to the hydrogen-flame test, which had shortly before been made available for use in mines by Professor Clowes, though it was found necessary to devise a special form of lamp for carrying out the test, and apparatus for the collection of samples of the atmosphere.

This decision was not arrived at until various other systems had also been tested. The author had long been accustomed to employ for the purpose an alcohol-flame, but the hydrogen-flame was found to be far more sensitive, and its action therefore more satisfactory.

The indications based upon the contraction of volume which takes place when air containing inflammable gas or vapour is brought into contact with a heated platinum wire, and a modification, suggested by Dr Dupré, involving the chemical estimation of the products of combustion, were found to possess disadvantages not shared by the hydrogen-flame test.

DEWAR'S APPARATUS.

Very promising results were obtained with a method of testing suggested to the author by Professor Dewar, which consisted in the employment of the sensitive form of manometer represented in Fig. 44. The instrument is provided, as will be seen, with a horizontal tube (A), of small bore ($\frac{1}{10}$ inch), open at one end, and communicating at the other with a small closed cistern (B), $1\frac{1}{2}$ inch in diameter. This cistern contains sufficient ether, or other mobile liquid, to cover the end of the horizontal tube, and to fill the tube up to the zero point on the scale. The cistern may be jacketed as shown, and a current of water caused to circu-

late through the annular space, to preserve uniformity of temperature.

Attached to the top of the cistern is a double-channel cock (c'). By means of this cock communication is established between the interior of the cistern and the external air, through a short lateral tube (d, d'), when the plug of the cock c is in the position shown in the detached figure. Or the interior of the cistern is made to communicate with a tube (e, e'), carried up to any desired vertical height, when the plug of the cock is placed in the position indicated in
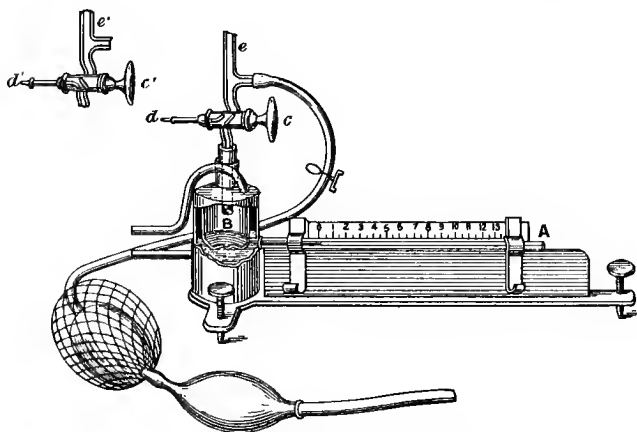
FIG. 44.—DEWAR'S TESTING APPARATUS.

the principal figure. It is obvious that with such an arrangement a means is provided of readily noting any increase in density of the column of air in the vertical tube.

Accordingly, if the position of the indicating column of liquid in the horizontal tube is recorded by the use of the attached scale, the effect produced by replacing the air in the vertical tube with a sample of air taken from a vessel containing a mixture of air and petroleum vapour can be readily observed. The sample is conveniently introduced by means of the blower shown in the figure. The air may,

of course, be previously deprived of water vapour and carbon dioxide.

The provision of the double-channel cock affords opportunity for checking and verifying the results, as the interior of the cistern may thus be placed alternately in communication with the air through the horizontal tube attached to the cock, and with the air column in the vertical tube, the liquid in the indicating tube being thus brought back to the zero point as often as may be desired.

This apparatus was fitted with a vertical tube, 10 feet in length, and the liquid in the horizontal tube was then found to travel a distance of ten of the divisions on the arbitrary scale, when a sample of air containing the vapour of three volumes of petroleum spirit (gasoline) in 100,000 volumes was tested. The delicacy of the test may evidently be increased by enlarging the area of liquid in the cistern in relation to that which is exposed to the air in the indicating tube; or by magnifying the movement of the liquid from the zero point on the scale by the use of a lens. The instrument may thus be made to furnish a quantitative test which, in respect to delicacy, does not compare unfavourably with the hydrogen-flame. On the other hand, the system is open to the objection that the apparatus described could not be used on board a vessel, unless it was either in perfectly still water or in dry dock.

Obviously this apparatus might, under certain circumstances, be advantageously placed for use in the atmosphere which it was desired to test; in which case the procedure would be reversed, the suspected air being displaced from the vertical tube by pure air from a supply which was carried in a state of compression in a small cylinder.*

* Under some conditions the long tube containing the sample of air, the density of which is to be observed, instead of being carried up vertically, would be more conveniently extended obliquely, or irregularly upwards; the sensitiveness of the instrument would then be governed by the difference in level between the surface of the sample of air and that of the indicating liquid.

Use of the Hydrogen-Flame Test, with Portable Collecting-Vessel.

The hydrogen-flame test, in common with the alcohol-flame test, has much to recommend it in preference to the other tests specified ; but it will suffice to say that in the practical experience of the author and his brother, a flame-test is found to be far more convincing, and to give much greater confidence, than any other form of test, to those engaged on board a steamship.

That this is a point of no small importance will be readily appreciated when it is borne in mind that, in the case of petroleum-tank steamships placed in dry dock for repairs, it is necessary that the atmosphere of the tanks and adjacent spaces should be tested before workmen are allowed to enter with naked lights or hot rivets.

Such testing is now invariably performed in this country before any internal repairs are effected in vessels which have carried petroleum in bulk, and as the lives of the workmen employed by the repairers, as well as the safety of the ship, would be imperilled by the employment of an unsuitable method of testing, or by the imperfect application of a satisfactory test, the subject is obviously one which cannot receive too careful consideration.

As already stated, the apparatus employed differs essentially from the miners' test-lamp devised by Professor Clowes, though in both cases a 10-mm. hydrogen-flame supplied from a cylinder of compressed gas is employed.

The following is a description of the form of apparatus which the author and his brother, in consultation with Professor Clowes and Messrs W. J. Fraser & Co., ultimately adopted.*

The complete appliances are shown in Fig. 45. They consist of the lamp A, the reservoir of compressed hydrogen

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* The apparatus described may be obtained from the sole makers, Messrs W. J. Fraser & Co., 98 Commercial Road East, London, E.

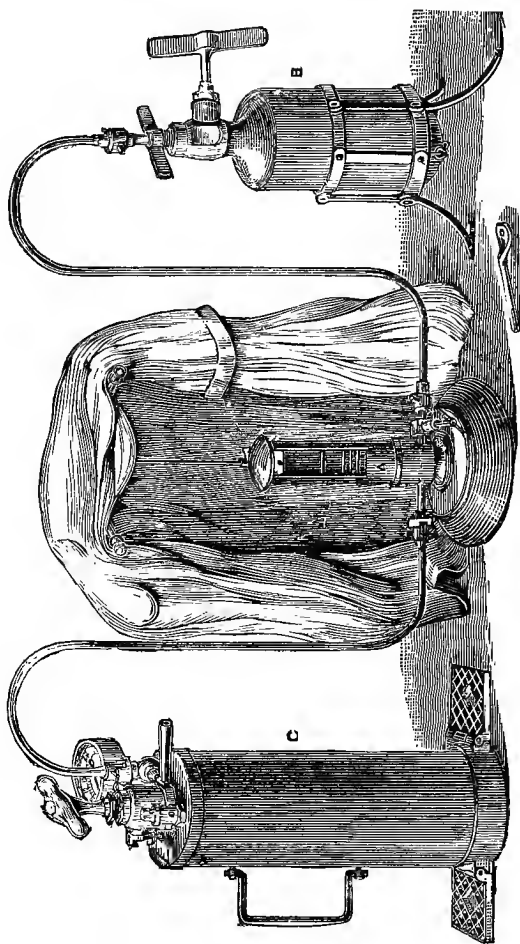B, and the sampling vessel C, in which the sample of air for examination is collected.

FIG. 45.

REDWOOD'S APPARATUS FOR TESTING THE ATMOSPHERE OF PETROLEUM-TANK STEAMSHIPS.

The lamp is shown in section in Fig. 46. A is the hydrogen inlet-tube with the regulating valve B, and C is

the hydrogen jet. D is the inlet-tube, for the sample of atmosphere to be tested. The bore of this tube is greatly contracted, and immediately above the point at which this tube enters the base of the lamp is an arrangement of baffles, surmounted by three discs of wire-gauze of at least 28 wires per lineal inch, or not less than 784 openings
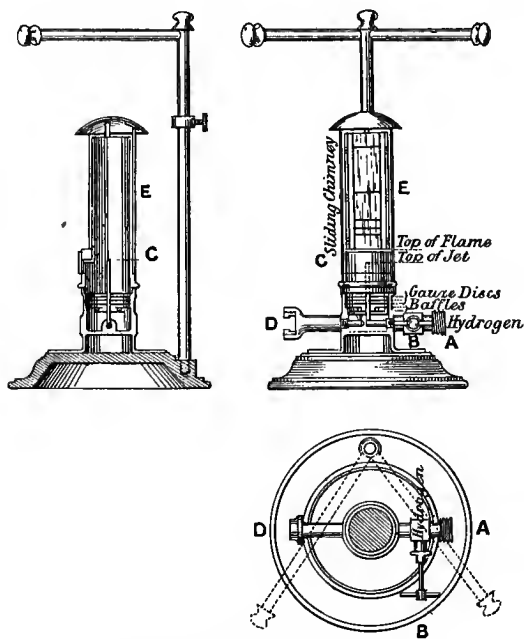

FIG. 46.—SECTION OF REDWOOD'S HYDROGEN-LAMP.

per square inch. The flow of the gaseous mixture to the flame is thus regulated, and passage of flame into the collecting vessel is prevented. The chimney E fits air-tight at the base, but is capable of vertical movement on an inner tube, the front of which is removed. The chimney is partly of metal and partly of glass, or other transparent

material. In the latest form of the apparatus, talc has been substituted for glass, with the object of preventing the deposition of the moisture produced by the combustion of
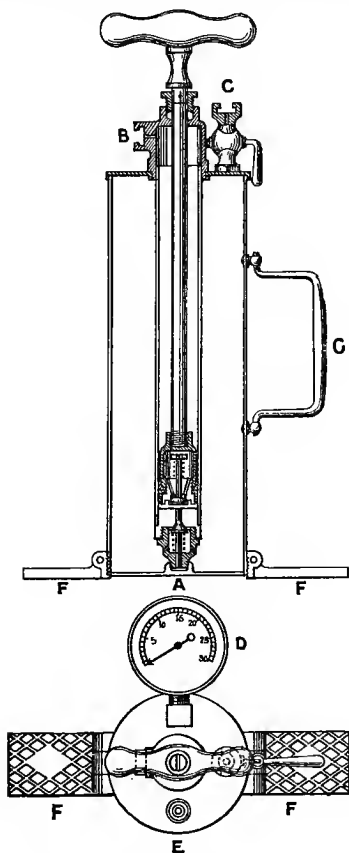

FIG. 47.—SECTION OF REDWOOD'S COLLECTING APPARATUS.

the hydrogen. The metallic portion of the chimney is blackened inside, and on the window lines corresponding with various heights of flame-caps may be marked. The

top of the hydrogen jet-tube is 10 millimetres (0.4 inch) below the bottom of the window.

Attached to the base of the lamp is a telescopic support for a cloth, which envelops the head of the observer and excludes light when the testing apparatus is used in an undarkened room.

The construction of the collecting-vessel is shown in section in Fig. 47. A is the compression-pump, which is furnished with a metallic spring-piston, fitting the pump-cylinder without the use of leather or other material, and lubricated with plumbago. Surrounding the pump is an annular space, in which the sample of atmosphere is stored. B is a collar to which may be attached a flexible suction-tube of any desired length. C is a cock, to which is attached a copper tube conveying the sample to the test-lamp. The bore of this cock is very much reduced. D is a pressure-gauge, and E a spring-valve lifting at 30 lbs. pressure. F F are hinged brackets, on which the feet of the operator are placed while the pump is being worked. G is a handle by which the cylinder can be conveniently carried.

The capacity of the pump is 14.84 cubic inches, and of the annular space 169.14 cubic inches. Thirty double strokes of the pump are required to charge the vessel to a pressure of 30 lbs. per square inch, when it will contain $\frac{1}{3}$ cubic foot of the atmosphere sampled. It is desirable that the collecting-vessel should be fitted with a relief valve, as the apparatus is often used in places in which the dial of the pressure-gauge cannot be easily seen. Above this valve a whistle is attached, which renders the escape of air through the valve audible.

Having regard to the well-known experiment of the ignition of a piece of tinder placed beneath the piston of an air-compression syringe, the author thought it expedient to ascertain the rise of temperature resulting from the compression of the sample, and, with the assistance of Messrs W. J. Fraser & Co., delicate thermometers were inserted at

suitable points, but the increase noted was only from 20° to 30° Fahrenheit.

The hydrogen-cylinder may be of any desired size, but the author has found that what is known as a 5-feet cylinder is of convenient dimensions. When charged to the usual pressure of 120 atmospheres, it holds enough gas to supply a 10-millimetre flame for ten hours, and is quite portable. The whole apparatus may be packed into two small boxes, and be readily taken on board a vessel.

In the use of the apparatus, the first step is to connect the hydrogen-cylinder with the lamp, taking care that the unions are screwed up gas-tight. The sliding chimney of the lamp being raised about half-way, the hydrogen gas is then cautiously turned on at the cylinder, the regulating valve on the lamp being left open, and a light is applied to the hydrogen-jet. The valve on the hydrogen-cylinder is then adjusted so as to give a flame rather more than 10 millimetres (0.4 inch) in length, and the lamp-chimney is pushed down until there is an opening of only about $\frac{1}{4}$ inch in height at the bottom. This opening is left for the supply of air to the hydrogen-flame during the few minutes occupied in the warming of the chimney. This preliminary warming, to prevent the deposition of moisture, is unnecessary if the apparatus is provided with a window of talc.

As soon as the transparent front of the chimney is quite clear, the lamp is ready for use, and assuming the collecting-vessel to have been already charged with the sample to be tested, and connected with the lamp, all that remains is for the observer to completely close the sliding chimney of the lamp, and adjust the hydrogen-flame by means of the regulating valve on the lamp, so that the tip of the flame is only just hidden when the eye of the observer is on a level with the bottom of the window. He then places his head under a cloth, such as used by photographers, so as to exclude light; and as soon as his eyes have become sufficiently sensitive, he turns on the tap of the collecting-cylinder, and carefully observes what takes place in the lamp-chimney. The tap

may at once be turned on fully, as the contraction of the outlet and inlet orifices, already referred to, prevents the sudden rushing out of the contents of the cylinder.

The sample of air will now be gradually delivered into the test-lamp during a period of more than two minutes, which is ample time for noting the effect.   The rate of delivery is, of course, a gradually diminishing one, but this is not found to be attended with any inconvenience, since the conditions are the same in each experiment.

In this way a proportion of vapour, considerably below that which is required even for the production of an inflammable mixture, and still lower than that which is needed to give an explosive atmosphere, may be detected by the formation of a flame-cap of greyish-blue colour.   This cap, though faint, is nevertheless easily seen, especially after a little practice.   With an increase in the quantity of vapour, the flame-cap first becomes much better defined, though it is not greatly augmented in size, and then considerable enlargement of the cap occurs, this condition being arrived at before the atmosphere becomes inflammable.

The author and his brother, Mr T. Horne Redwood, succeeded some time ago in obtaining photographs of flame-caps produced by the presence of pentane vapour in various proportions in air, and these photographs were reproduced in colour to illustrate a paper read by the author before the Institution of Civil Engineers.   In the frontispiece of this work, which has been adapted from the lithograph referred to, A represents the standard (10 milli-metre) hydrogen-flame, burning in air free from petroleum vapour, and B, C, D, E, F, show the flame-caps produced, with a hydrogen-flame of this height, when the air contains 0.05, 0.1, 0.3, 0.6, and 0.8 per cent. respectively of pentane vapour.

These illustrations not only convey an accurate impression of what the observer has to look for in employing the hydrogen-flame in the quantitative testing of air containing, or suspected to contain, petroleum vapour, but give the actual dimensions of the flame-caps produced with the

specified proportions of petroleum vapour in the air. It should, however, be stated that the petroleum vapour flame-caps appear to be somewhat less sharply pointed than those shown in the lithograph.

A reference to the results obtained by the author, which are given in the table in the Appendix to this chapter (p. 195), will show that even the proportion of vapour which furnished the large flame-cap F is considerably below that necessary for the formation of a mixture which was combustible under the conditions of the experiments, and far smaller than that which produced an explosive mixture. The test is, therefore, a delicate one, and it is obvious that if the interior of a tank or other space be ventilated until a sample of the atmosphere gives no flame-cap with this apparatus, an ample margin of safety will be provided, even allowing for the fact that on the large scale, under some circumstances, combustion might occur when the proportion of vapour was smaller than the minimum quantity found to be requisite in the experiments made.

In taking a sample of the air in a tank it must be remembered that the density of the vapour of petroleum is always much greater than that of the air. The density of the vapour is dependent upon the chemical composition of the hydrocarbons volatilised. Thus the vapour of pentane (C_5H_{12}), a hydrocarbon of the paraffin series present in American crude petroleum, and of which gasoline is largely composed, is 2.5 times heavier than air, whilst that of heptane (C_7H_{16}) is 3.4 times heavier than air.

The collecting-vessel may be used in the tank if the proportion of vapour present is known to be small, but even in such cases it is better to employ a short suction-tube, the open end of which can be placed at the lowest point in the tank, where the heavy vapour would probably be found in largest quantity. If, on the other hand, the atmosphere of the tank is suspected to contain so much vapour, that there would be danger of its producing insensibility when taken into the lungs, and especially if the compartment is

entered through a small manhole, it would obviously be most improper that any one should be sent into the tank, and in that case the sample should be taken by the use of a long suction tube reaching to the bottom.

It is evident that in the case of those tank-steamships which have spaces not filled with oil, but in which oil-vapour is liable to accumulate, there would be no difficulty in having a system of tubing of small diameter permanently fitted. This would be so arranged, as to admit of a sample of the atmosphere of any space being drawn off by means of the collecting-cylinder, in a place in the ship set apart for testing purposes, so that periodical tests might thus be made during the voyage.

This apparatus has now been in use for several years, and has given the most satisfactory results. In reporting upon a serious accident which occurred on board the S.S. "Tancarville," through the explosion of a mixture of petroleum vapour and air, the Inspectors for the Board of Trade made the following suggestion :—

" When repairs require to be carried out in a vessel which has been carrying petroleum, there should, in our judgment, be a formal handing over of the vessel to those by whom the repairs are to be undertaken, and a certificate that the tanks and all dangerous spaces have, so far as practicable, been adequately cleansed and ventilated and rendered free from risk of explosion or fire. If from any cause a complete certificate of this sort cannot be given, then it should be clearly notified which tanks or spaces have not been cleansed and are still dangerous."

This recommendation has been generally adopted, and such certificates are now given.

The apparatus described above, or the portable form of which particulars are given hereafter, may be employed in detecting the presence and determining the proportion of inflammable gas present in the atmosphere of the coal-bunkers of steamships, or for examining the atmosphere of sewers or electric culverts.

Use of the Hydrogen-Flame Test in a Portable
Apparatus, without a Collecting-Vessel.

Another important application of the hydrogen-flame test has lately arisen in connection with the alarming explosions which have occurred in street culverts carrying the electric-light wires. These explosions have been due to the ignition of a gaseous mixture which has accumulated in the chambers, and it is obvious that they might have been prevented if the presence of inflammable gas had been disclosed by the periodical testing of the atmosphere of such spaces, and means had been adopted to remove such accumulation by ventilation.

Recent regulations made by the Board of Trade under the Electric Lighting Acts, 1882 and 1888, provide that:—

" All conduits, pipes, casings, and street-boxes used as receptacles for electric lines shall be constructed of durable material, and where laid under carriage ways shall be of ample strength to prevent damage from heavy traffic ; and reasonable means shall be taken by the undertakers to prevent accumulation of gas in such receptacles.

" When street-boxes are used as transformer-chambers, reasonable means shall be taken to prevent as far as possible any influx of water, either from the adjacent soil or by means of pipes ; and in the case of any such street-box exceeding one cubic yard in capacity, ample provision shall be made, by ventilation or otherwise, for the immediate escape of any gas which may by accident have obtained access to the box, and for the prevention of danger from sparking.

" All street-boxes shall be regularly inspected for the presence of gas, and if any influx or accumulation is discovered, the undertakers shall give immediate notice to the authority or company whose gas mains are laid in the neighbourhood of the street-box."

Experiments made by the author and his brother with samples of air taken from the culverts in question in the
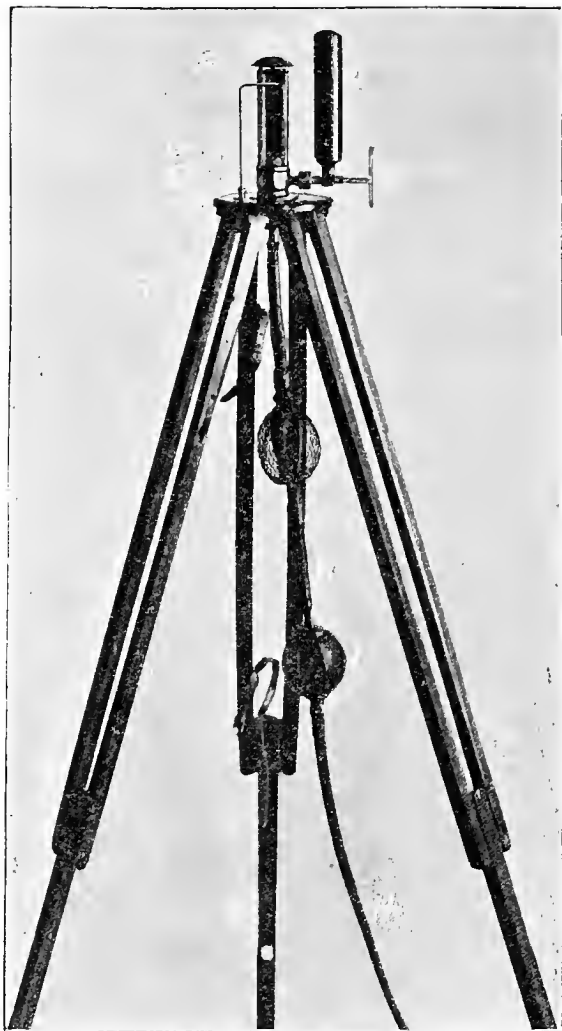
FIG. 48.—CLOWES-REDWOOD PORTABLE TESTING APPARATUS.
TOTAL WEIGHT, 11 LBS.

City of London, and by Dr Clowes in the Nottingham street-boxes, demonstrated that the hydrogen-flame test affords a perfectly trustworthy means of determining the proportion of inflammable gas present ; but as the apparatus already described was not suitable for use in the testing of the atmosphere of electric-light street-boxes *in situ*, Messrs W. J. Fraser & Co. directed their attention to the designing of a portable form of the apparatus, which is represented in Fig. 48.

The following is a description of the apparatus :—The test-lamp (B), which is ordinarily carried in a small case, is firmly attached to the base (G), which is supported by a tripod stand (E). The lower part of the lamp shown at D is fitted with discs of wire gauze to prevent the passage of flame, and the hydrogen-jet tube extends vertically upwards through the centre of these.

The supply of compressed hydrogen is contained in a small pocket cylinder (A), which is connected with the lamp by a union. It can readily be detached, and replaced by a fresh one when it is exhausted. The size of the hydrogen-flame is regulated by a loose key (K), as is shown in the figure.

The front of the lamp is provided with a talc window, through which the flame-cap is observed. At the base of this window there is a small brass screen (C), sliding vertically in grooves. When this screen is at the highest point to which it can be raised, and the hydrogen supply is so adjusted that the top of the flame is only just hidden when the eye of the observer is on a level with the top of the screen, the height of the flame will be 10 millimetres (= 0.4 inch), and when the screen is similarly employed at the lowest point the flame will be 5 millimetres (= 0.2 inch) in height.

At the side of the lamp is a rod (F), bent at a right angle at the upper end, which slides in a stuffing box, and forms a convenient gauge of the height of the flame-cap.

Attached to the base of the lamp is an indiarubber tube

(H), which is provided with a collapsible ball (I), fitted with valves, by means of which a current of air may be drawn from any receptacle and driven into the lamp. The ball is squeezed firmly by the whole hand as soon as it has completely expanded. An expanding ball (J) is also provided for regulating and maintaining the speed of the air-current.

In using the apparatus the chimney is turned round its axis so as to open an air-hole, which keeps the hydrogen-flame burning until the air-sample is to be blown in. By rotating the chimney this hole is closed, as soon as all is ready for blowing in the air. The air-current must be blown over the hydrogen-flame for a short time to remove the air contained in the rubber-tube and balls. The cap is measured as soon as its height remains constant.

In the use of the apparatus for testing the atmosphere of electric-light street-boxes, the lower end of the tube is passed through an orifice in the lid of the box. A cloth, such as is used by photographers, is thrown over the top of the apparatus and over the head of the operator. Light is thus so effectually excluded that a flame-cap corresponding with 0.5 per cent. of inflammable gas can be clearly seen even when the apparatus is used in bright daylight. The larger hydrogen-flame should be first employed, and if the flame-cap is too long for measurement, the smaller flame should be made use of.

The whole of the appliances only weighs 11 lbs.

Experiments with this apparatus were made with air containing known percentages of coal-gas. The flame-cap heights observed corresponded precisely with those given on page 73. No cap could be produced, however, with 6 per cent. of gas. This mixture flared throughout the interior of the chimney.

It is evident that the rubber-tube may be introduced into any space into which a man could not enter at all, or at any rate enter with safety, and a stream of air could be drawn thence and tested. Such unapproachable places exist in

electric street-boxes, coal-mines, gas-works, coal-bunkers of steamers, and furnace flues (p. 78). In all these cases inflammable gases may be tested for and measured with the greatest ease by this portable apparatus. Information regarding the method of procedure in testing such gases, and the flame-caps which are observed, will be found on page 57 for firedamp, on page 74 for coal-gas, and on pages 76 to 79 for water-gas, acetylene, and flue-gases.

APPENDIX TO CHAPTER VIII.

Explosion in Petroleum Steamers. Experiments on Evaporation and Explosibility of Petroleum Vapour in Air.

By Boverton Redwood.

In illustration of the importance attaching to the detection and measurement of petroleum vapour in the atmosphere of oil-tanks and other spaces in steamships and elsewhere, the following excerpts from a paper contributed by the author to the Institution of Civil Engineers, are reproduced from the Minutes of Proceedings of the Institution, by permission of the Council.

The "Tancarville" case is quoted as being of a typical character, but many other examples illustrative of the danger arising from the presence of petroleum vapour in the air will be found on referring to the paper. Cases are also given of serious accidents resulting from the firing of air containing other inflammable vapour, such as that of naphtha, carbon bisulphide, ether, alcohol or methylated spirit, and whisky.

In all these cases the danger would have been avoided by testing the atmosphere by the means already described before introducing a flame or other source of ignition.

THE "TANCARVILLE" EXPLOSION.

In May 1891 an explosion of great violence, but very local in its effect, occurred on board the S.S. "Tancarville." The vessel is an iron-tank steamship, designed for the carriage of petroleum in bulk, and built in 1889. Previously to the occurrence of the accident she had been employed in the carriage of crude petroleum from Philadelphia to Havre, and having discharged her last cargo, she was brought to Newport, Monmouthshire, and was placed in dry-dock for repairs. Workmen had been engaged upon her, in the oil-tanks and elsewhere, for twenty days, and the necessary repairs had been almost completed, when, on the morning of the 11th of May, the explosion took place.

The author made an examination of the vessel on the same day. From the appearances presented, it was evident that the explosion occurred in a water-ballast tank, forward of what was known as No. 1 oil-tank, from which it was only separated by a single bulkhead. It is, however, possible that the explosion

actually started in the bunker above the water-ballast tank. The explosive effect seemed to have been mainly localised on the port side of the water-ballast tank, and to have been exerted principally upwards and aft. The two expansion trunks, which were situated in the bunker on the port and starboard sides respectively of the deck forming the cover of the water-ballast tank, were evidently blown up to a considerable height, and were lying in the dry-dock, one on each side of the vessel, somewhat astern of the seat of the explosion. The forward bulkhead of No. 1 oil-tank was blown into the tank on the port side, and the skin of the ship was far more injured on this side than on the starboard side.

It appeared that before the work of repairing was commenced the whole of the oil-tanks were cleaned in the usual manner, by washing them with a jet of water supplied by the donkey-pump, men being sent into the tanks to direct the stream so as to ensure that the whole surface of the tanks should be properly washed down. Afterwards the tanks were dried with sawdust and cotton waste. Previous to, during, and subsequent to, the cleaning, the tanks were ventilated with wind-sails. During the summer months the water-ballast tank already referred to was used as a cargo tank, and it had been last employed thus in October 1890 ; but it was asserted that in February 1891, when the vessel was discharging a cargo of crude oil at Havre, some one from the shore, unknown to the officers of the ship, opened a valve and allowed a quantity of oil to flow into the ballast-tank.

The piping employed in the discharge of the cargo extended through all the oil-tanks and into the water-ballast tank, but in the latter the suction was about $4\frac{1}{2}$ inches above the bottom instead of being about $1\frac{1}{2}$ inches, as was the case in the oil-tanks. It was therefore evident that the ballast-tank could not be emptied by means of the pumps. After discharging her last cargo, the ballast-tank had been filled with water ; but if an attempt had been made to displace the oil with water, and cause it to overflow into the 'tween decks, a considerable quantity of oil would necessarily be confined between the beams in the upper part of the tank, and thus prevented from flowing away.

The cleansing and ventilation of the ballast-tank would have presented considerable difficulties, and it was apparently not thought necessary to attempt these operations ; but two days

before the explosion took place, a hole was drilled through the skin of the vessel at the bottom of the ballast-tank, and the contents of that tank were allowed to run out into the dock. It should be added that the vessel was lighted throughout by electricity on the double-wire system, portable cables and glow-lamps being used in the tanks.

The repairs necessitated a large amount of riveting, and several portable forges were used on the upper deck. On the morning of Monday, 11th May, men were sent into No. 1 oil-tank to clean up some oil which had leaked into that tank from the ballast-tank, through a defective rivet-hole in the bulkhead, before the latter tank had been emptied as already described. Ten men and boys then commenced work in the tank, and as one of these was cutting a thread in a rivet-hole, with the object of replacing a defective rivet with a screw-plug, a tongue of flame appeared to issue from the hole, scorching his hand ; the flame then seemed to recede through the hole, and immediately a very violent explosion took place. Of the ten men and boys in the tank at the time, four were killed, and others were injured, while a carpenter, who was at work in the 'tween decks on the port side over the bunker space, also lost his life.

The evidence given at the Board of Trade inquiry conclusively demonstrated that the accident was due to the ignition of an explosive mixture of petroleum vapour and air in the ballast-tank, but did not clear up the question of how the ignition took place. [Report to the Assistant Secretary (Marine Department) Board of Trade, 31st July 1891.]

Samples of the petroleum were examined by Dr Dupré and by the author, with the result that it was ascertained that one gallon of such oil would render 200 cubic feet of air feebly, and about 58 feet of air strongly, explosive ; therefore 20 cubic feet of oil would have sufficed to render the atmosphere of the water-ballast tank, the capacity of which was about 6,000 cubic feet, explosive.

It seems probable that the atmosphere on both sides of the ballast-tank was not equally explosive. The tank was divided in the centre by a vertical fore and aft bulkhead, and if the existence of a merely inflammable atmosphere on the starboard side of this bulkhead, and of a violently explosive mixture on the port side, be assumed, a condition of things which is consistent with the statement that the manhole on the starboard side was

open, while that on the port side was closed, it is easy to understand that there may have been first an ignition of the contents of the starboard tank, producing the flame which passed through the rivet-hole into No. 1 oil-tank, and afterwards an explosion of the contents of the port tank.

As has been already mentioned, it is possible that the ignition originated in the bunker above the ballast-tank. This space was provided with a hatchway in the centre, the expansion trunks of the ballast-tank, which opened into the bunker, not being beneath the hatchway, but to port and starboard respectively. It is difficult to understand how, with an open hatchway of considerable size, there could have been any large accumulation in the bunker of vapour which had diffused into it from the ballast-tank beneath, but it should be borne in mind that on the morning of the explosion the sun was shining brightly, and the weather was warmer than it had been just previously. The atmosphere of the ballast-tank was therefore probably undergoing rapid expansion under the influence of the elevation of temperature, and it is conceivable that an inflammable or explosive mixture of petroleum vapour and air may have been overflowing into the bunker. How this mixture, assuming it to have flowed into the bunker, became ignited, remains a mystery ; the official inquiry was, however, prolific in suggestions relative to the construction and management of petroleum tank steamships.

EXPERIMENTS ON EVAPORATION OF PETROLEUM, THE FORMATION OF INFLAMMABLE AND EXPLOSIVE MIXTURES OF VAPOUR AND AIR, AND THE IGNITION OF SUCH MIXTURES.

The accidents caused by petroleum vapour indicate clearly that certain descriptions of petroleum evaporate freely at common temperatures ; that the vapour given off is much heavier than air, and may remain for a considerable length of time in any receptacle capable of holding a liquid, or may flow unperceived for some distance in a stream similar to that of a liquid ; that the vapour is highly inflammable and capable of carrying back flame to the source whence it emanated ; and that mixtures of petroleum vapour and air may be either inflammable and burn silently, or may be more or less violently explosive.

Many accidents have been due to the presence of vapour given off by crude petroleum, or by petroleum spirit (benzoline). It must not, however, be assumed that all precautions which have reference to the possible accumulation of vapour are unnecessary in the case of refined petroleum oil (kerosene). Crude petroleum consists almost entirely of a mixture of a great number of hydrocarbons, differing in boiling point and density. Its percentage chemical composition, as a whole, is usually, carbon 85 parts by weight, and hydrogen 15 parts. Some descriptions of crude petroleum contain exceedingly volatile liquid hydrocarbons, which are separated in the process of refining, and are met with in commerce as gasoline, benzoline, &c.; dissolved gaseous hydrocarbons are also sometimes present, and these are readily liberated. It is therefore not surprising that a portion of such crude petroleum freely evaporates. The density of the vapour is dependent upon the chemical composition of the hydrocarbons volatilised.

With a view of gaining information respecting the manner in which crude petroleum and various products of petroleum evaporate, a series of comparative experiments was carried out by the author and Mr Blundstone, at known temperatures. The liquids experimented with were pentane, gasoline (specific gravity at 60° Fahrenheit 0.639), petroleum spirit (specific gravity at 60° Fahrenheit 0.680), benzoline (specific gravity at 60° Fahrenheit 0.700), and crude American petroleum (specific gravity at 60° Fahrenheit 0.801). The apparatus employed consisted of a range of six graduated tubes, which could be maintained at a constant temperature in a large glass tank containing water, and through which a known volume of dry air could be caused to pass at any desired rate in a steady stream. The quantity of air which had travelled through the liquid, bubble by bubble, was periodically ascertained, and the volume of liquid evaporated in each tube was at the same time noted. The determinations were made with each liquid at the temperatures of 40°, 60°, 80°, and 100° Fahrenheit.

The relative quantities of the various liquids evaporated under the conditions of the experiments are shown in Fig. 49.

The results, as a whole, demonstrate, as might have been anticipated, that the air very readily takes up a large proportion of the vapour which it is capable of holding, but that the complete saturation is afterwards effected comparatively slowly.

The quantities of the hydrocarbon taken up at the various temperatures are in excess of those which air is usually considered to be capable of holding, when in the condition of what is termed air-gas ; but there was no appearance of distillation, though the high atmospheric temperature prevailing at the time
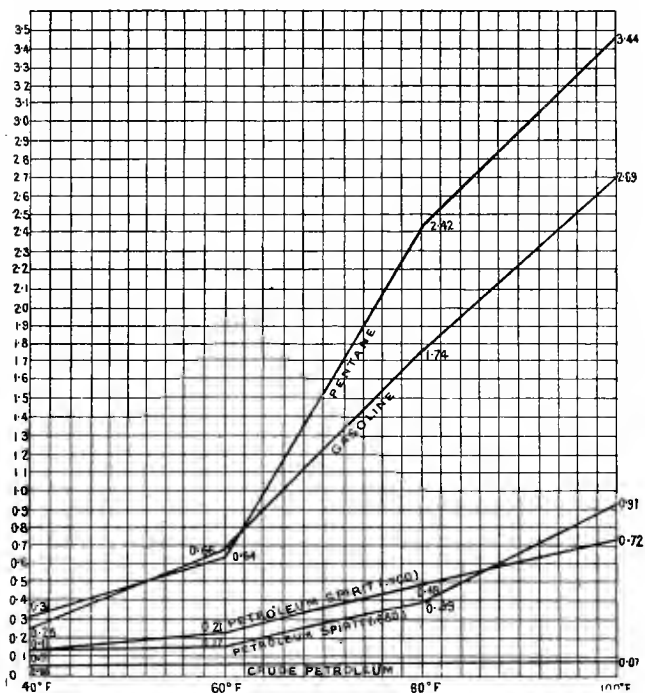

FIG. 49.—VOLUME OF LIQUID EVAPORATED BY 100 VOLUMES OF AIR, BASED UPON THE FIRST SET OF READINGS AT EACH TEMPERATURE.

of the experiments would prevent any condensation of liquid in the exit tube of the apparatus.

It is quite possible that a portion of the liquid may have been carried over mechanically, though the undiminished quantities in tubes five and six in the first set of readings at 40° appear to indicate that, if this occurred at all, it must have been to a very

slight extent, and in any case the conditions probably approximated very closely to those which prevail when petroleum products are being pumped from one vessel to another in large quantities.

Experiments made by Dr Dupré with the object of ascertaining the proportions of petroleum spirit (benzoline) which, in a state of vapour, would suffice to render air inflammable or explosive, showed that 1 volume of liquid benzoline will render 16,000 volumes of air inflammable, or 5,000 volumes strongly explosive. When 1 volume of the liquid is evaporated in 3,000 volumes of air, the mixture is inflammable, but scarcely explosive.

Similar experiments have been made by the author. These determinations clearly demonstrated that, when the vapour given off by crude petroleum or by a freely volatile product of petroleum is allowed to diffuse into air in a confined space, the atmosphere first becomes gradually converted into an inflammable mixture which ignites and burns rapidly, but without any audible explosion. As the proportion of vapour to air increases, there is a corresponding acceleration in the transmission of flame through the gaseous mixture, accompanied by a gradually augmenting volume of sound, until the proportions necessary for the production of the most violent explosion are reached. Beyond this point any increase in the proportion of vapour is accompanied with a diminution in the energy of the combustion, and an increase in the duration of the flame.

The mixture, therefore, becomes first inflammable, but not explosive ; next explosive ; and finally again only inflammable. It is also found that during the progress of the diffusion of vapour from a layer of petroleum at the bottom of a tank into the air in the tank above the liquid, the proportion of vapour in the atmosphere is not uniform throughout unless the gaseous contents of the tank are mixed by agitation, the greater proportion of vapour being at the bottom.

The experimental determination of the respective volumes of a given description of petroleum, required for the production with a given volume of air of gaseous mixtures, which under given conditions are (a) just inflammable, (b) violently explosive, and (c) again only inflammable, can be effected with tolerable facility with some kinds of petroleum, and under certain conditions of temperature ; but the bulk of the mixture, or, in other

words, the scale on which the tests are made, and the method of ignition adopted, are not without material effect upon the results.

Thus the introduction of a large flame may bring about the combustion of a mixture containing a small proportion of vapour which a small flame will not ignite, and a mixture which burns silently in small bulk may be consumed with a rapidity approaching to explosive violence when a large volume of it is ignited. In the case of a liquid of uniform composition which wholly volatilises with freedom at common temperatures, such as pentane, it is obviously not difficult to introduce gradually increasing volumes into a given volume of air, and test the character, as to inflammability, of the resulting gaseous mixtures ; but with crude petroleum, which is of variable composition, and of which only a small proportion passes into vapour by a process of fractional evaporation, and even with a less complex liquid such as commercial benzoline, it is by no means an easy matter to make experiments the results of which would be of much practical value, except as a basis of comparison. With the object, however, of illustrating the general character of the results which may be obtained with mixtures of the vapour of crude petroleum and of certain of the more volatile products of petroleum, the author has, with the assistance of Mr Blundstone, carried out a series of experiments.

The apparatus employed for the experiments consisted of a glass rotary churn, in which the liquid was agitated with air, vessels for displacing a known volume of the gaseous contents of the churn, and an explosion chamber, in which the character of the combustion of mixtures of " air-gas " produced in the churn, with air in various proportions, was tested. The air-gas was displaced from the churn by the introduction of the requisite volume of the liquid under experiment from a graduated glass vessel, the air-gas being driven direct into the explosion chamber in some cases, and in others being stored for a short time in a gas-holder containing water covered with a layer of the liquid from which the vapour was produced.

The explosion chamber consisted of a square vessel of stout tin-sheet of 1 cubic foot capacity, fitted with an efficient agitator for mixing the contents, a loose cover provided with a water-seal, tubes for the introduction of the air-gas and escape of the displaced air, and a circular vent 3 inches in diameter, through

which the igniting flame was introduced.   The lack of strength
in the materials of which the chamber was constructed did not
admit of the cover being heavily weighted, and thus, even with
so large a vent, it was impossible to differentiate between the
explosive violence exerted by the combustion of several of the
mixtures.   The results given were nevertheless in many respects
very instructive.

With the explosion chamber already described a series of
experiments was also made by the author with various volumes
of liquid pentane and commercial gasoline introduced directly
into the chamber by means of a graduated pipette, and the
results in the table on the next page were thus obtained.

It will be noted that with 7 volumes of the liquid to 100,000
volumes of air the combustion is a silent one, while with four
times that proportion of liquid the mixture also burns without
explosive violence.   With between 8 and 9 volumes of liquid to
100,000 of air there is a marked increase in the energy of the
combustion, and when the quantity of liquid is augmented to
10.5 volumes a sharp explosion occurs.   When the proportion
of liquid is increased beyond about 17 volumes there is a per-
ceptible decrease in the violence of the explosion, with corre-
sponding gain in the volume and duration of the flame, and
with 21 volumes of liquid to 100,000 of air the explosion is as
mild as with 8.4 volumes.

There was no appreciable difference in the violence of the
explosion produced with a number of the intermediate mix-
tures.   The author hopes, however, to have an opportunity of
continuing the experiments with an explosion chamber of
stronger construction, and better adapted for the measurement
of force exerted by the explosion.

Comparing certain of the results obtained with the liquid
with those given by the air-gas, it is evident that the air in the
churn took up far less vapour than was removed by a similar
volume of air passed through the series of tubes in the experi-
ments already described.   It also appears from a comparison of
the results obtained with the air-gas and those yielded when the
liquid is evaporated in the explosion chamber that there is, in
the latter case, a smaller difference between the proportion of
vapour requisite for the production of an inflammable mixture,
and that which gives a mixture exploding with the maximum
violence ; but this apparent discrepancy may be due to the

limited scope which the conditions of the experiments afforded
for recording the results with any approach to precision when a
more or less violent explosion occurred.

EXPERIMENTS WITH PENTANE AND GASOLINE EVAPORATED IN AN EXPLOSION CHAMBER.

Weight on cover = 8 lbs.   Temperature, 65° Fahrenheit.

Volume of Liquid Evaporated in 100,000 Volumes of Air.	Percentage Volume of Vapour in the Air.	Results obtained on Testing the Mixture with the Flame of a Taper.
3.5	0.672	No ignition.
5.6	...	Ditto.
5.95	...	Slight combustion round large flame.
6.3	...	More marked combustion round flame.
6.65	...	Very sluggish combustion, extending through the mixture.
7.0	1.345	Quiet combustion, scarcely audible; duration about two seconds.
7.7	...	Hissing sound; water blown out of seal; cover not lifted.
8.4	...	Hissing sound; water blown out of seal; cover barely lifted.
9.1	...	Louder hissing sound of shorter duration; cover lifted.
9.8	...	Ditto.
10.5	2.017	Sharp explosion.
11.2	...	Ditto.
11.9	...	Ditto.
12.6	...	Ditto.
13.3	...	Ditto.
14.0	2.690	Ditto.
14.7	...	Ditto.
15.4	...	Ditto.
16.1	...	Ditto.
16.8	...	Ditto.
17.5	3.362	Slightly less violent explosion, but cover lifted, and outburst of flame.
18.2	...	Ditto.
18.9	...	Ditto.
19.6	...	Roaring sound; cover slightly lifted.
20.3	...	Ditto.
21.0	4.034	Prolonged roaring sound; cover practically not lifted.
28.0	5.379	Mixture ignited silently at vent, and flame then travelled into the chamber, where the mixture continued burning quietly for three seconds.

In the case of a petroleum product of known chemical composition there is, of course, no difficulty in ascertaining by calculation the proportions of vapour and air requisite for the production of the most violent explosion, if we assume that in such case the hydrocarbon is burned to carbon dioxide and water. Thus, in the case of pentane (C_5H_{12}), we find that 1 cubic foot of air, at 60° Fahrenheit and 30 inches barometric pressure, is required for the conversion of 34.5 grains (3.5 cubic centimetres at 60° Fahrenheit) into CO_2 and H_2O. This is equivalent to 12.25 volumes of liquid to 100,000 volumes of air, and on referring to the preceding table it will be seen that these proportions gave in the author's experiments a violent explosion.

The successive stages of (1) uninflammability, (2) silent combustion, (3) more or less violent explosion, (4) silent combustion, (5) uninflammability (except on the surface exposed to the air), occurring during the addition to air of increasing proportions of petroleum vapour, are similar to those which have been observed in experiments with mixtures of combustible gases and air. Thus it has been ascertained that if to the violently explosive mixture of 2 volumes of hydrogen and 1 volume of oxygen, 8 volumes in excess of hydrogen, or 9 volumes in excess of oxygen, be added, the mixture is rendered non-inflammable, provided that the temperature of the gases does not exceed 18° Centigrade, and the pressure is not above 14.7 lbs. per square inch. A mixture which is not, under such conditions, combustible, may, however, be brought into an inflammable state by increase of temperature or pressure, and it has been found that flame may be propagated through a mixture, which by an ordinary test would appear to be uninflammable, by projecting into the mixture a considerable volume of burning gas, in consequence of the resulting increased temperature and pressure.

Messrs Mallard and Le Châtelier also ascertained that the rate of propagation of flame through an inflammable gaseous mixture was affected, not only by the temperature and size of the igniting flame, but also by the mechanical agitation or disturbance of the mixture itself. These results are not surprising when it is considered that it is necessary for the spread of combustion in an inflammable gaseous mixture that the temperature of the combustion should be sufficient to ignite the uninflamed portion.

According to Messrs Berthelot and Vieille, when an explosion of a gaseous mixture occurs, a number of ignited molecules are projected forward with a velocity corresponding with the maximum temperature produced by the chemical combination, the impact causing the ignition of the adjacent particles, and the rate of progression of the combustion being thus dependent upon the activity of the chemical action.

The experiments made by Mr Hirn with the view of determining the pressures resulting from the explosion of gaseous mixtures in closed vessels showed that there was a considerable difference between the theoretical and observed results, which he ascribed to the cooling effect exerted by the walls of the containing vessel. Similar differences were observed by Mr Dugald Clerk (*Minutes of Proceedings Inst. C.E.*, vol. lxxxv., p. 1 *et seq.*). Messrs Berthelot and Vieille also ascertained experimentally that the reduction of pressure due to loss of heat by radiation and absorption by the walls of the vessel is in proportion to the area or surface of the vessel, in relation to the volume of gaseous mixture, and to the slowness of the combustion.

With petroleum oil (kerosene) it is difficult to produce on a small scale an inflammable mixture of vapour and air at temperatures more than a very few degrees below the flashing point of the oil (Abel test), even when vigorous agitation is resorted to ; but when large volumes of the oil are violently agitated, as in the operation of pumping from one tank to another, vapour appears sometimes to be disengaged at a somewhat lower temperature. The result may, in part at any rate, be due to the liberation of traces of gaseous hydrocarbons dissolved in the oil. With such opportunities for the diffusion of the vapour as ordinarily exist during the operations which tend to its disengagement, it is, however, unlikely that an explosive atmosphere would be created at temperatures below the flashing-point of the oil, or even somewhat above that point ; and in any case it is evident that a very moderate amount of ventilation would obviate any risk which might otherwise arise.*

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* A fire which occurred at a petroleum storage installation at Harburg in May 1895 points to the conclusion that an explosive mixture of petroleum vapour and air may be formed in storage tanks at a temperature far below the flashing point of the oil.

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